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Grassland, Soil and Water Research Laboratory

Agricultural Research Service

USDA
United States Department of Agriculture

Report of the ARS GLOBAL CHANGE RESEARCH WORKSHOP
Temple, TX
September 23-25, 1997

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Compiled and edited by:

H. Allen Torbert
Temple, TX
December 1997

PREFACE

PREFACE

This volume contains the documentation from the fourth Global Change Research Planning Workshop held at Temple, Texas, in September 1997. The workshop meets several needs, but its primary purpose is to provide the ARS scientists who conduct research in global change, hydrology, and water management an opportunity to interact and exchange information and ideas. At the same time, progress is assessed and new priorities are informally identified as a basis for planning and making program adjustments. The workshop also allows an appraisal of whether the program is meeting its overall goals of reducing uncertainty regarding the effects of global change on agriculture and future food security, documenting the extent and nature of agriculture's role in causing global change by generating greenhouse gas emissions and forestalling climate change by sequestering greenhouse gases, and determining how effects of global change may be mitigated or how agriculture can adapt to large-scale environmental changes.

The ARS Global Change Research Program addresses a wide range of more specific global change-related questions and problems in both plant and animal agriculture. It utilizes state-of-the-art scientific technology, and has developed several unique approaches to the study of hydrologic processes, global change effects on plants, and trace gas emissions and the carbon cycle. These specific objectives and novel experimental approaches appear in the 68 progress reports submitted by the ARS scientists and engineers who conduct the Global Change National Program. It directly involves over 30 researchers assigned to 16 Research Units at 13 different locations across the U.S. Also included in these progress reports are contributions from over 70 additional ARS scientists and engineers who work in closely related areas, especially the Water Quality and Management, the Air Quality, the Methyl Bromide Alternatives, and the Integrated Farm Systems National Programs. These progress reports document the current status of ARS' efforts to resolve uncertainty concerning the potential effects of climate change, rising atmospheric carbon dioxide levels, tropospheric ozone, uv-B radiation, and other large-scale environmental changes on crop and animal production systems, grazinglands, hydrology, and ecosystems processes. They also indicate that research continues to provide policy makers with information regarding the positive effects of global change. Examples include various aspects of the "fertilization effect" of rising atmospheric carbon dioxide concentrations on plants and possible improvements in the capacity to produce crops in interior Alaska, as suggested by recent evidence of increases in the number of degree growing days. The work addresses very basic phenomena like plant photosynthesis, respiration, and metabolism, as well as practical operations like tillage, irrigation and fertilization. It involves scientific disciplines ranging from fundamental (chemistry, molecular biology, genetics, plant physiology) to the applied (agronomy, water management, rangeland management).

Working as members of teams, and with a host of cooperators, these scientists have compiled an impressive record of achievement in improving our level of understanding of global

change effects, and in understanding the role of agriculture as a contributor to the causes of global change. To date, these researchers have:

- enhanced our knowledge of fundamental biological processes critical to agriculture, such as photosynthesis, respiration, and growth; enzymatic processes; stress tolerance; plant competition, water use, and the acquisition and use of light energy and nutrients,

- increased our understanding of biogeochemical processes important to agriculture, such as energy exchange between the terrestrial surface and the atmosphere; carbon and nutrient cycles; trace gas fluxes and their sources, sinks, and pools; and especially the hydrological cycle,

- acquired long-term hydrologic, climatic and vegetation databases useful for documenting change and developing an understanding of hydrologic processes and climatic effects on crop and livestock production,

- documented how changing atmospheric carbon dioxide concentrations affect plant physiology, growth, partitioning of photosynthate, biomass accumulation and yield, water use, and energy capture,

- determined how uv-B radiation and atmospheric ozone affect plant physiological processes and crop yields, and how uv-B radiation and ozone interact with rising atmospheric carbon dioxide levels and other global change effects,

- determined how global change factors such as uv-B radiation, changing temperature and precipitation patterns, and changes in the trace gas composition of the atmosphere interact with other stresses on crops and animals, such as diseases, weeds, insect infestations, salinity, and drought,

- provided accurate measurements of amounts of greenhouse gases such as carbon dioxide, methane, and nitrous oxides that are emitted into the atmosphere by agricultural activities, and accurate estimates of amounts removed from the atmosphere by agricultural practices that sequester greenhouse gases, such as the shift from conventional to minimum tillage and conversion of cropland to perennial grasses or trees under the Conservation Reserve Program,

- determined the effects of rising atmospheric carbon dioxide levels on ecosystem processes which control productivity, structure, and species composition of vegetation on rangelands, and

- developed a suite of simulation models which allow the prediction of global change effects on crop growth and yield, livestock production, water availability, and the sustainability of agricultural production systems, and of the effects of global change

and change-induced shifts in production and conservation practices on natural resources (soil, water, air, vegetation) and environmental quality.

Also included in these proceedings are the recommendations and other results of discussions by the three working groups, defined by the traditional components of the global change research program, Hydrologic Processes, Ecosystem Dynamics, and Biogeochemical Cycles. Those reports refer to preliminary deliberations by the three groups on the critical question, "what are we doing to provide solutions to problems that may be caused by global change impacts on agriculture and water supplies?" ARS global change research has appropriately focused on understanding global change impacts since its beginning. But we soon will be asked to place more emphasis on development of methods to mitigate or adapt to global change effects, and to document the tools and products we have developed which farmers and ranchers, resource managers, and policy makers might employ to avoid any negative effects. Documentation of such products will be requested from all Federal departments and agencies involved in the U.S. Global Change Research Program, as attention inevitably shifts from understanding adverse effects to insuring that we are prepared for them. It is time to begin identifying specific deliverables that have been or will be produced by ARS research.

Other possible sources of influence upon our research became apparent in both formal and informal discussions at the workshop and elsewhere. For instance, we increasingly will be called upon to conduct our research in ways which provide data that are more useful to those economists who are concerned about how global change effects might impact the costs and efficiency of agricultural production and the behavior of national and international agricultural markets. In this vein, efforts to incorporate economic components into our models should be redoubled. USDA may be asked to supplement or enhance its programs which address the capability of conservation practices and policies to sequester atmospheric carbon dioxide as soil organic matter, in response to an international treaty to reduce greenhouse gas emissions which may accommodate sequestration and the trading of carbon credits in agriculture as well as energy and other industries. Similarly, the possibility of climate change due to an intensified greenhouse effect has underscored the potential of biofuels for both energy conservation and economic benefit as a new market for agriculture. Finally, USDA has recently been asked by the Administration to join other departments of Federal government in a structured process of assessing climate change impacts on many sectors of the national economy, including the availability of food and water, and to do so on both regional and national scales. This intensive activity will last several years, and will require the participation of ARS scientists, in a manner similar to the contributions we make to the international assessments conducted by the Intergovernmental Panel on Climate Change.

Herman Mayeux
National Program Leader, Global Change
Beltsville, MD

ACKNOWLEDGMENTS

ACKNOWLEDGMENTS

Many individuals contributed to the success of the fourth ARS Global Change Research Planning Workshop. Clarence Richardson, Laboratory Director, and the entire staff of the Grassland, Soil and Water Research Laboratory in Temple, Texas, did a tremendous job of organizing the meeting. They spared no effort to provide adequate facilities, an excellent technical tour, and enjoyable social events. Allen Torbert, Soil Scientist at Temple, TX, compiled, edited, and distributed these proceedings. Gerald Schuman, Research Leader of the Rangeland Resources Research Unit at Cheyenne, WY, organized and led the activities of the Biogeochemical Cycles working group, replacing Ron Follett, Research Leader of the Soil, Plant, and Nutrient Research Unit in Fort Collins, CO, who served in that capacity for many years. Jack Morgan, Plant Physiologist with the Rangeland Resources Research Unit at Fort Collins, CO, substituted most capably for Basil Acock, Plant Physiologist with the Remote Sensing and Modeling Laboratory, Beltsville, MD, by leading the activities of the Ecosystem Dynamics working group. Keith Cooley, Hydrologist at the Northwest Watershed Research Center at Boise, ID, and Al Rango, Hydrologist at the Beltsville, MD, Hydrology Laboratory, coordinated the activities of the Hydrologic Processes working group, as they have done so well for all previous workshops. Finally, the accomplishments of the workshop are primarily attributable to the commitment and energy of the 52 attendees.

MEETING AGENDA

ARS GLOBAL CHANGE RESEARCH WORKSHOP
Temple, TX
September 23-25, 1997

Tuesday, September 23

8:00am	Introductions and Local Arrangements	Clarence Richardson
8:10am	Welcome	George Foster Acting Associate Area Director, SPA
8:15am	Purpose and Outcomes	Dave Farrell/Herman Mayeux
8:30am	Current Status and National Priorities of the ARS Hydrology and Climate Programs	Dave Farrell
8:45am	Current Status and National Priorities of the ARS Global Change Research Program	Herman Mayeux
9:00am	Progress Reports on Large-scale, Integrated Experiments	
	The Southern Great Plains Experiment	Pat Starks
	JORNEX, The Jornada Experiment	Al Rango
	SALSA	Dave Goodrich
10:00am	Break	
10:30am	Enhanced Interaction Among Ecosystems, Biochemistry, and Hydrology/Climate Groups	Gerald Schuman
11:00am	The National Research Programs	Dave Farrell/Herman Mayeux
11:45am	Locations of Concurrent Sessions	Clarence Richardson
12:00 pm	Lunch	
1:30 pm	Concurrent Sessions	
	Biogeochemical Fluxes	Gerald Schuman
	Ecosystem Dynamics	Jack Morgan
	Hydrological Processes and Climate	Keith Cooley and Al Rango
3:00pm	Joint Break	
3:20pm	Resume Concurrent Sessions	
4:30pm	Joint Session for Group Progress Reports and Discussion	
5:00 pm	Adjourn	
6:00pm	Group Dinner - Stagecoach Inn, Salado, TX	

Wednesday, September 24

TECHNICAL TOUR

8:15am	Begin tour from Inn at Scott & White (See separate schedule for details)
4:00pm	Return to the Inn at Scott & White
6:00pm	Depart from Inn at Scott & White for Texas Bar-B-Q

Thursday, September 25

8:00am	Concurrent Sessions	
10:00am	Joint Break	
10:30am	Resume Concurrent Sessions	
12:00pm	Lunch	
1:30pm	Joint Session - Group Reports and Identification of New Priorities	
	Biogeochemical Fluxes	Gerald Schuman
	Ecosystem Dynamics	Jack Morgan
	Hydrological Processes and Climate	Keith Cooley and Al Rango
2:30pm	Concluding Remarks and Discussion	Dave Farrell/Herman Mayeux
3:30pm	Impressions	George Foster
4:00pm	Adjourn	

LIST OF ATTENDEES

Carlos Alonzo
USDA-ARS-MSA
P. O. Box 1157
Oxford, MS 38655

L. Hartwell Allen, Jr.
USDA-ARS-SAA
University of Florida
Box 110965
Gainesville, FL 32611-0965

Raymond Angell
USDA-ARS
HC71, 4.51 Hwy. 205
Burns, OR 97720

Jeff Arnold
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

John Baker
USDA-ARS
Borlaug Hall
1991 Upper Buford Circle
St. Paul, MN 55108

James Bradford
USDA-ARS-SPA
2000 18th Street
Woodward, OK 73801

Steve Britz
USDA-ARS
B-046-A, BARC-West
Beltsville, MD 20705

James Bunce
Climate Stress Lab
BARC-West
10300 Baltimore Avenue
Beltsville, MD 20705-2350

Pat Clark
USDA-ARS
800 Parl Blvd, Plaza IV,
Suite 105
Boise, ID 83712-7716

Keith Cooley
USDA-ARS-PWA
800 Park Blvd. Pl., Suite 105
Boise, ID 83712

J. A. Daniel
USDA-ARS-SPA
7207 W. Cheyenne
El Reno, OK 73036

Sharon Drumm
USDA-ARS-NPS
10300 Blatimore Blvd.,
B-005
Beltsville, MD 20705

William Emmerich
USDA-ARS-PWA
2000 E. Allen Rd.
Tucson, AZ 85719

David Farrell
USDA-ARS-NPS-NRS
Bg. 005, Rm 201,
BARC-West
Beltsville, MD 20705

George Foster
USDA-ARS-SPA
7607 Eastmark Dr., Suite 230
College Station, TX 77840

A. B. Frank
USDA-ARS
Nat. Res. Mgt.
P. O. Box 459
Mandan, ND 58554

David Goodrich
USDA-ARS-PWA
2000 E. Allen Road
Tucson, AZ 85719

Marshall Haferkamp
USDA-ARS
Rt. 1, Box 2021
Miles City, MT 59301

Ardell Halvorson
USDA-ARS-NPA
P. O. Box 459
Mandan, ND 58554

Stuart Hardegree
USDA-ARS-PWA
800 Park Blvd. Pl. IV,
Suite 105
Boise, ID 83712

Allen Heagle
USDA-ARS
1216 Scott Place
Cary, NC

Gordon Hutchinson
USDA-ARS-NPA
P. O. Box E
Ft. Collins, CO 80522

Douglas Johnson
USDA-ARS-NPA
Utah St. Univ. Forage &
Range Res. Lab
Logan, UT 84322-6300

Hyrum Johnson
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Tim Keefer
USDA-ARS-PWA
2000 E. Allen Road
Tucson, AZ 85719

Bruce Kimball
USDA-ARS-PWA
4331 E. Broadway R
Phoenix, AZ 85040

Kevin King
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Jim Kiniry
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Herman Mayeux
USDA-ARS-NPS
Bldg. 005, Rm. 325, BARC-West
Beltsville, MD 20705

Joe Miller
USDA-ARS-SAA
1509 Varsity Dr.
Raleigh, NC 27606

Jack Morgan
USDA-ARS-NPA
1701 Centre Ave.
Ft. Collins, CO 80525

Arvin Mosier
USDA-ARS-NPA
P. O. Box E
Ft. Collins, CO 80522

Ludmila Pachepsky
USDA-ARS
Bldg. 007, Rm. 008, BARC-West
Beltsville, MD 20705-2350

Rod Pennington
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76592

Paul Pinter
USDA-ARS
U.S. Water Conserv. Lab
4331 E. Broadway Road
Phoenix, AZ 85040

Wayne Polley
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Kenneth Potter
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Albert Rango
USDA-ARS
Bldg. 007, Rm. 104
Beltsville, MD 20705

Clarence Richardson
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Hugo H. Rogers
USDA-ARS-MSA
Nat. Soil Dynamics Lab
P. O. Box 3439
Auburn, AL 36831

Nicanor Saliendra
USDA-ARS
Forage and Range
Utah State University
Logan, UT 84322-6300

Gerald Schuman
USDA-ARS-NPA
High Plns. Grassland Res. Station
8408 Hildreth Rd.
Cheyenne, WY 82009-8899

Marvin Shaffer
USDA-ARS-NPA
P. O. Box E
Ft. Collins, CO 80522

Ronald Sharpe
USDA-ARS-SAA
1420 Experiment Station Rd.
Watkinsville, GA 30677

Phillip Sims
USDA-ARS-SPA
2000 18th Street
Woodward, OK 73801

Charles Slaughter
USDA-ARS-NWRC
800 Park Blvd. Pl. IV, Suite 105
Boise, ID 83712

Patrick Starks
USDA-ARS-SPA
7207 W. Cheyenne
El Reno, OK 73036

Tony Svejcar
USDA-ARS
HC 71, 4.51, Hwy. 205
Burns, OR 97720

Charles Tischler
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Allen Torbert
USDA-ARS-SPA
808 East Blackland Road
Temple, TX 76502

Mark Weltz
USDA-ARS-PWA
2000 E. Allen Road
Tucson, AZ 85719

Lewis Ziska
USDA-ARS
Climate Stress Lab
B-046-A, BARC-West
10300 Baltimore Avenue
Beltsville, MD 20705

OPENING REMARKS

Dr. D. A. Farrell, National Program Leader

Opening Remarks at Global Change Meeting
September 26-28, 1997 at Temple, TX

Introduction:

The challenges that all federal agencies face relate to the continued relevance of their primary missions, their success in achieving their goals, and the enthusiasm that their activities generate within their major clientele, namely, the key communities that they serve, legislative bodies, and the general public. Science agencies, such as ARS are subject to the same pressures as most other federal agencies. The future of ARS as a major role player in water resources research will depend on how successfully those of us who are directly involved with this work meet these challenges.

After almost two years of work, the committee appointed by the National Research Council to review the water resources work of the U.S. Geological Survey has published its report. This report, entitled "Watershed Research in the U.S. Geological Survey" was released in June, 1997. The findings and recommendations of this report provide valuable insights and guidance for the water resources programs of ARS and other science agencies. In the Executive Summary of the report, the committee identifies three issues that deserve serious consideration by the scientists and managers of the ARS water resources programs. The first of these issues relates to the need for strengthening collaboration with other federal agencies. The three science agencies identified in the report are the Agricultural Research Service, the Forest Service, and the National Science Foundation. The second issue relates to coordination with consumers to assure the relevancy of the agency's work. The third and final issue relates to the assistance that the agency can provide in properly educating the next generation of water resources professionals. The implications for ARS are clear. Collectively, this agency's water resources specialists have the skills, knowledge, and experience to make major contributions to collaborative research, improved coordination with consumers, and the education of future professionals. The question that must be answered is "Does the agency's professional staff have the will and commitment to accept the challenge?"

The questions addressed by the Committee's report are relevant to all water resources agencies. The following questions, extracted from the report, clearly affect watershed research in ARS:

- What should be the underlying strategy for USGS watershed research activities? What are the key design elements for an effective program in watershed science?

- What are the major opportunities for advances in the USGS's capability in watershed science?

- How should activities in water research support ongoing USGS programs, especially the NAWQA (National Water Quality Assessment) program and the long-term observing networks, and vice-versa?

- What should be the appropriate links with programs in watershed research and management in other agencies and institutions?

- What are the appropriate internal USGS links, given the broad array of watershed-related research going on within the agency?

- What are the implementation requirements for effective operation of watershed research activities to address important management issues?

Some of the Committee's recommendation's that are directly related to the activities of ARS include:

Recommendation 1.2 The USGS should make it a high priority to develop research watersheds in coordination with other federal agencies, especially the U.S. Department of Agriculture through the Agricultural Research Service (ARS) and the Forest Service (FS). In addition, strong links should be maintained and expanded to National Science Foundation Long-Term Ecological Research sites and existing ARS and FS watersheds. The USGS can add significantly to the current resources in place at ARS and FS research sites. Strong consideration should also be given to inclusion of staff from other agencies at existing USGS watersheds. In this regard the USGS should examine its incentive structure and consider creating or enhancing staff rewards for collaborative interagency efforts.

Recommendation 2.2 The level of effort in the modeling aspects of watershed activities may have to be increased substantially. Testing and verifying models across a range of scales should be a primary goal of the overall effort.

Recommendation 4.1 The USGS has taken an active role in providing technical assessments of alternatives in some areas where whole watershed restoration efforts are underway. As this role expands, the USGS should commit to improving the science base supporting assessment protocols for watershed-scale restoration. The USGS should advance the science of whole-watershed restoration in four critical areas, (1) improvements in the ability to understand relationships among watershed hydrology, water quality, and habitat; (2) helping better understand conditions prior to disturbance; (3) relating the consequences of restoring damaged sites to watershed scale outcomes; and (4) translating knowledge gained from data collection and experimental watershed studies into models that can be used to evaluate restoration actions. The new capabilities brought to the agency by the Biological Resources Division should be very helpful in the work on watershed restoration.

Recommendation 5.1 The USGS should develop an integrated effort on sediment transport. This effort should include a measurement program for a hierarchy of basins around the United States, nested so as to address issues of scaling from small watersheds to large watersheds. The measurement program should be supplemented with a modeling effort to interpret the measurements, and to provide the framework for scaling process understanding from small to large watersheds. Special consideration should be given to urban watersheds where improved knowledge of sediment budgets may be of critical importance in understanding the effects of development on water quality and channel stability.

Adjustments to programs and priorities in other parts of the world might also be considered in developing a future ARS research agenda in scientific hydrology and watershed research. The 1995/1996 annual report from the Institute of Hydrology at Wallingford in the United Kingdom provides some insights that might be included as discussion topics for the special session on hydrology and global change.

Institute of Hydrology, Wallingford

In 1994, the Natural Environment Research Council consolidated four institutes into the Centre for Ecology and Hydrology. The four insitutes are: the Institute of Freshwater Ecology, Institute of Hydrology, Institute of Terrestrial Ecology, and the Institute of Virology and Environmental Biochemistry. Research issues that are expected to be central to the future role of the Institute of Hydrology as part of the new Centre for Ecology and Hydrology include:

- Below ground competition for water, and research into processes governing uptake of water by competing root systems;

- The vulnerability of groundwater-fed river systems in lowland Britain and the expansion of our catchment research into permeable areas;

- The challenge of developing integrated water quality models to aid environmental management at catchment or basin scale;

- Investigations into the role of snow and and permafrost in global climate processes, extending our overseas work from tropical and arid regions to the Arctic;

- The increasing importance of the socio-economic dimension in our work, especially as this relates to water, urbanisation and health.

The Institute of Hydrology is divided into four divisions, the Engineering Hydrology Division, the Environmental Hydrology Division, the Land Use and Experimental Hydrology Division, and the Hydrological Processes Division. The major objectives of the research within these four divisions are as follows:

Engineering Hydrology Division

1. Development of techniques for estimating the extremes of low flow discharges for given frequencies and durations at both gauged and ungauged sites;

2. Derivation of new generalized methods of rainfall and flood frequency estimation;

3. Assessment of the impacts of climate change on water resources and flood frequency;

4. Development of models for assessing the impact of artificial influences including land use change and resource development.

5. Development of techniques for assessing the impact of river flow regimes and channel morphology on freshwater ecology;

6. Development of procedures for estimating and forecasting precipitation rates using radar and raingauge information;

7. Combination of hydrologic models with data acquisition systems to develop real-time flood forecasting and drought management systems;

8. Improvement in the effectiveness of hydrological design by transferring the results of hydrological research to European and overseas applications and practitioners.

Environmental Hydrology Division

1. Development of models that describe the key hydrological, physical, chemical, sedimentological, and biological mechanisms that determine water quality and that can be applied within a GIS framework to provide tools to answer scientific, operational, and strategic management questions;

2. Assistance in the design of water quality monitoring networks and in the interpretation of water quality databases through trend analysis and modelling;

3. Quantification of the fluxes of pollutants and chamicals transported to estuaries;

4. Investigations and improved understanding of the processes controlling the behaviour of inorganic and organic polutants in river systems;

5. Investigations of the mechanisms by which chemicals and other pollutants are transported from land surfaces and soils into the fluvial system;

6. Determination of the potential impact of environmental change, including industrial, social policy, land-use, atmospheric deposition and climate change, on water quality.

Land Use and Experimental Hydrology Division

1. Development of a holistic understanding of the impact of land use and other anthropogenic changes on hydrology, both within the United Kingdom and overseas, as a means toward improving both quality of life and economic wellbeing;

2. Improved predictions of the impact of land use change upon catchment water yield, floods, low flows, subsurface water, and waterborne fluxes;

3. Development of and support for state-of-the-art hydrological instrumentation systems to further the institute's science and for commercial exploitation.

Hydrological Processes Division

1. Quantification of the effects of soil physical and plant physiological processes on the hydrological cycle, especially where dominated by trees and shrubs;

2. Measurements and models of the hydrological processes occurring within and between the complete mosaic of land use systems within entire landscapes, e.g. forestry, agriculture;

3. Improvement in our ability to predict the hydrological consequences of environmental change at local and regional scales, with emphasis on the use of remote sensing techniques, regional data sets, and GIS;

4. An increased understanding of hydrological processes at regional and global scales through field experiments and modelling so as to foster improved representation of these processes in the global climate and continental scale models that are used to predict future climates and regional water resources.

The 1994-95 Annual Report of the Institute of Hydrology includes interesting information on the relationship between radar-based estimates of soil moisture in the top 5 cm of the soil and stored soil water in the top 50 cm of the soil profile. The microwave radar measurements were obtained from an instrument on the European Space Satellite, ERS-1. The Institute developed a two-layer dynamic soil water model for determining stored soil water from radar-based estimates of surface soil moisture that appears to fit well with the reported observations for both a sandy soil and a clay soil. The same report contains summary information on the Hydrological Radar Experiment (HYREX) conducted by the Institute using a network of 50 recording raingauges distributed within the Brue catchment of 132 sq km in Somerset, England. The HYREX experiment used three different radar systems for estimating rainfall. In bringing these issues to your attention, I am encouraging you to reach out to scientists across the world.

Many of the scientists participating in this workshop were actively involved in developing the ARS document entitled "Water Resource Challenges and Opportunities for the 21st Century". Even though that document was developed more than six years ago, many of the research and technology needs related to global change have not changed significantly. The two primary elements of the Global Change-Water Resources and Agriculture program that were identified by the participants at that workshop were: Element 1 - Predict water and energy fluxes to, within, and from managed ecosystems; and Element 2 - Evaluate scale effects of hydrologic processes.

These challenges and opportunities are as important to scientific hydrology, water resources management, and global change today as they were six years ago. The 1997 recommendations of the Academy of Sciences Committee that reviewed the water resources programs of the U.S. Geological Survey, endorsed the need for strengthening research on scaling issues. The future research mission of the Institute of Hydrology includes several research challenges associated with the scaling needs of hydrological processes, and the application of hydrologic principles at landscape, catchment, basin, regional, and global scales. Those of you who attended the "Hydrology Days" conference at Fort Collins, Colorado in April may remember the strong statements by David Mathews of the World Bank and others regarding the critical need for better hydrologic understanding of water resources at national, regional, and continental scales if the problems of economic development in many regions of the world are to be successfully addressed. I remain firmly convinced that, without population stabilization, water resources will be the dominant resource issue of the 21st century. The challenge to all of us is to build the scientific base that will permit, encourage, and promote sound, prudent, and optimal management of this vital resource by future generations.

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1. Watershed Research in the U.S. Geological Survey. 1997. National Academy Press.

2. 1995-96 Annual Report. Institute of Hydrology, Wallingford, United Kingdom.

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4. Water Resource Challenges and Opportunities for the 21st Century. ARS 101, Mar. 1992

ARS Global Change-Water Resources and Agriculture Program

High Priority Hydrologic Research-1991 Workshop

Element 1	**Predict water and energy fluxes to, within, and from managed ecosystems; and**
Element 2	**Evaluate scale effects of hydrologic processes.**

QUESTIONS RAISED IN NAS REPORT

- What should be the underlying strategy for USGS watershed research activities? What are the key design elements for an effective program in watershed science?

- What are the major opportunities for advances in the USGS's capability in watershed science?

- How should activities in water research support ongoing USGS programs, especially the NAWQA (National Water Quality Assessment) program and the long-term observing networks, and vice-versa?

- What should be the appropriate links with programs in watershed research and management in other agencies and institutions?

- What are the appropriate internal USGS links, given the broad array of watershed-related research going on within the agency?

- What are the implementation requirements for effective operation of watershed research activities to address important management issues?

Recommendation 1.2

The USGS should make it a high priority to develop research watersheds in coordination with other federal agencies, especially the U.S. Department of Agriculture through the Agricultural Research Service (ARS) and the Forest Service (FS).

In addition, strong links should be maintained and expanded to National Science Foundation Long-Term Ecological Research sites and existing ARS and FS watersheds. The USGS can add significantly to the current resources in place at ARS and FS research sites.

Strong consideration should also be given to inclusion of staff from other agencies at existing USGS watersheds. In this regard the USGS should examine its incentive structure and consider creating or enhancing staff rewards for collaborative interagency efforts.

Recommendation 2.2

The level of effort in the modeling aspects of watershed activities may have to be increased substantially. Testing and verifying models across a range of scales should be a primary goal of the overall effort.

Recommendation 4.1

The USGS has taken an active role in providing technical assessments of alternatives in some areas where whole watershed restoration efforts are underway. As this role expands, the USGS should commit to improving the science base supporting assessment protocols for watershed-scale restoration.

The USGS should advance the science of whole-watershed restoration in four critical areas:

(1) improvements in the ability to understand relationships among watershed hydrology, water quality, and habitat;

(2) helping better understand conditions prior to disturbance;

(3) relating the consequences of restoring damaged sites to watershed scale outcomes; and

(4) translating knowledge gained from data collection and experimental watershed studies into models that can be used to evaluate restoration actions.

The new capabilities brought to the agency by the Biological Resources Division should be very helpful in the work on watershed restoration.

Recommendation 5.1

The USGS should develop an integrated effort on sediment transport. This effort should include a measurement program for a hierarchy of basins around the United States, nested so as to address issues of scaling from small watersheds to large watersheds.

The measurement program should be supplemented with a modeling effort to interpret the measurements, and to provide the framework for scaling process understanding from small to large watersheds.

Special consideration should be given to urban watersheds where improved knowledge of sediment budgets may be of critical importance in understanding the effects of development on water quality and channel stability.

Institute of Hydrology, Wallingford

- Below ground competition for water, and research into processes governing uptake of water by competing root systems;

- The vulnerability of groundwater-fed river systems in lowland Britain and the expansion of our catchment research into permeable areas;

- The challenge of developing integrated water quality models to aid environmental management at catchment or basin scale;

- Investigations into the role of snow and and permafrost in global climate processes, extending our overseas work from tropical and arid regions to the Arctic;

- The increasing importance of the socio-economic dimension in our work, especially as this relates to water, urbanisation and health.

Engineering Hydrology Division

1. **Development of techniques for estimating the extremes of low flow discharges for given frequencies and durations at both gauged and ungauged sites;**

2. **Derivation of new generalized methods of rainfall and flood frequency estimation;**

3. **Assessment of the impacts of climate change on water resources and flood frequency;**

4. **Development of models for assessing the impact of artificial influences including land use change and resource development.**

5. **Development of techniques for assessing the impact of river flow regimes and channel morphology on freshwater ecology;**

6. **Development of procedures for estimating and forecasting precipitation rates using radar and raingauge information;**

7. **Combination of hydrologic models with data acquisition systems to develop real-time flood forecasting and drought management systems;**

8. **Improvement in the effectiveness of hydrological design by transferring the results of hydrological research to European and overseas applications and practitioners.**

Environmental Hydrology Division

1. **Development of models that describe the key hydrological, physical, chemical, sedimentological, and biological mechanisms that determine water quality and that can be applied within a GIS framework to provide tools to answer scientific, operational, and strategic management questions;**

2. **Assistance in the design of water quality monitoring networks and in the interpretation of water quality databases through trend analysis and modelling;**

3. **Quantification of the fluxes of pollutants and chamicals transported to estuaries;**

4. **Investigations and improved understanding of the processes controlling the behaviour of inorganic and organic polutants in river systems;**

5. **Investigations of the mechanisms by which chemicals and other pollutants are transported from land surfaces and soils into the fluvial system;**

6. **Determination of the potential impact of environmental change, including industrial, social policy, land-use, atmospheric deposition and climate change, on water quality.**

Land Use and Experimental Hydrology Division

1. Development of a holistic understanding of the impact of land use and other anthropogenic changes on hydrology, both within the United Kingdom and overseas, as a means toward improving both quality of life and economic wellbeing;

2. Improved predictions of the impact of land use change upon catchment water yield, floods, low flows, subsurface water, and waterborne fluxes;

3. Development of and support for state-of-the-art hydrological instrumentation systems to further the institute's science and for commercial exploitation.

Hydrological Processes Division

1. Quantification of the effects of soil physical and plant physiological processes on the hydrological cycle, especially where dominated by trees and shrubs;

2. Measurements and models of the hydrological processes occurring within and between the complete mosaic of land use systems within entire landscapes, e.g. forestry, agriculture;

3. Improvement in our ability to predict the hydrological consequences of environmental change at local and regional scales, with emphasis on the use of remote sensing techniques, regional data sets, and GIS;

4. An increased understanding of hydrological processes at regional and global scales through field experiments and modelling so as to foster improved representation of these processes in the global climate and continental scale models that are used to predict future climates and regional water resources.

GLOBAL CHANGE ISSUES AND DELIVERABLES

ISSUES AND DELIVERABLES

Dr. H. S. Mayeux requested information from each working group on issues and deliverable products in each technical area. Specific requests by working group were as follows.

Hydrologic Processes

What is being done to assess climate change effects on water supplies and water quality?

Biogeochemical Cycles

What is being done to document:
1) Agricultural greenhouse gas emissions
2) Ways to reduce atmospheric concentrations

Ecosystem Dynamics

What is being done to document
1) Interactions among global change effects, especially temperature and precipitation changes
2) Impacts of temperature, precipitation, and increased variation in weather

All Three Groups

Deliverables for the above that represent options for mitigation or adaption to climate change effects.

Examples of ways we provide farmers with tools or methods to deal with climate change impacts: previous, existing, and expected.

The responses are given on the first page of the Annual Research Reports for each working group. The Hydrologic Processes Group also assembled responses from individual research locations and/or scientists. Ninteen individual location/scientists responses were submitted. These responses are available upon request from Dr. H. S. Mayeux (phone: 301-504-5281; email: hsm@ars.usda.gov).

RESEARCH PROGRESS REPORTS

- ECOSYSTEM DYNAMICS
- BIOGEOCHEMICAL CYCLES
- HYDROLOGIC PROCESSES

ECOSYSTEM DYNAMICS

ECOSYSTEM DYNAMICS

In addition to the annual reports from each project, each of the three working groups of the USDA/ARS Global Change Program were asked to provide additional information concerning assessment and documentation of global change issues relevant to each of the three groups as well as well as products for end-users. Specific requests follow.

I. Requests for assessment and documentation of the Ecosystem Dynamics Group include:

1) interactions among global change effects, especially temperature and precipitation changes, and
2) impacts of temperature, precipitation, and increased variation in weather.

II. All three working groups were also asked for:

1) deliverables for the above that represent options for mitigation or adaptation to climate change effects, and
2) examples of ways we provide farmers and ranchers with tools or methods to deal with climate change impacts; previous, existing and expected.

Following are our responses to these two requests.

I. ASSESSMENT OF GLOBAL CHANGE RESEARCH IN ECOSYSTEM DYNAMICS

A table summarizing research activities of the different Ecosystem Dynamics Groups is provided as a brief response to the first issue of assessment. The groups listed are ones which were represented by presentations at the 1997 meeting in Temple, TX. Other information includes experimental environment, major species and/or systems investigated, what major environmental factors were being evaluated and in combination with what other global change interactions, and lastly, what are the focuses of the various projects. Although the questions submitted to this group emphasized issues of variable weather, particularly temperature and precipitation, Table 1 reveals a host of studies whose main thrusts are in the areas of CO_2 enrichment, ozone and solar radiation. There is already considerable information of plant and ecosystem responses to various aspects of weather, although much of that work was not done in the context of global change. That body of knowledge is available and can be used for extrapolating to various global change scenarios. The issues this group has focused on, CO_2 enrichment, effects of ozone and changes in radiation quantity and quality, are ones which are not as well researched or understood. Some of the projects have involved interactions with other environmental traits (e.g., water, temperature). Information provided in all of these projects, in addition to the information already contained in the literature and which focuses more on climate and other environmental aspects, will allow an assessment of global change responses, including weather.

TABLE 1. SUMMARY OF ECOSYSTEM DYNAMICS PROJECTS

Presenters/ Collaborators	Location	Experimental Environment	Major Species & Systems	Environmental Factors	Focus
B.Kimball P.Pinter S.Idso G.Wall R. LaMorte N.Adam F.Adamsen D.Hunsaker F.Nakayama	U.S. Water Conservation Lab Phoenix, AZ	FACE Open-top Chamber	cotton/wheat (past) sorghum (present) sour orange (since 1987)	Major: CO_2 Interactions: water, N	growth, yield, development, physiology, radiation use efficiency, micromet, water
A.Torbert H.Rogers S.Prior D.Reeves R.Raper D. Reicosky D.Stott	Grassland, Soil & Water Research Lab, Temple, TX & ARS National Soil Dynamics Lab Auburn, AL	FACE Open-top Chamber	soybean, sorghum, wheat, clover conventional vs. sustainable tillage agro-forest	Major: CO_2 Interactions: water, nutrients	belowground soil & plant processes (roots, rhizosphere micro., soil properties, nutrient cycling)
J.Morgan G.Schuman D.LeCain J. Reeder H.Skinner G. Hutchinson J. Hanson W.Hunt	Rangeland Resources Research Unit Cheyenne Wy & Ft. Collins, CO	Growth Chamber Open-top Chamber Field	C_3 & C_4 shortgrass steppe grasses, esp. blue grama & western wheatgrass grazed vs. ungrazed	Major: CO_2 Interactions: water, N & temperature	growth, physiology, defoliation & regrowth, biomass & nutrient partitioning
J. Bunce L. Ziska C. Sicher	Climate Stress Lab Beltsville, MD	Greenhouse Open-top Chamber	soybean, barley, potato, wheat, corn, sorghum C_3 & C_4 crops vs. weeds	Major: CO_2 Interactions: water, temperature	growth, physiology, intraspecific differences, stomatal physiology, acclimation, respiration

Presenters/ Collaborators	Location	Experimental Environment	Major Species & Systems	Environmental Factors	Focus
W. Polley H. Johnson C. Tischler R. Pennington	Grassland, Soil & Water Research Lab, Temple, TX	Greenhouse CO_2 tunnels Field	cotton, bagbod sesbania, mesquite, cucumber, hemp sesbania, bluebunch wheatgrass, threadleaf snakeweed, rangeland spp.	Major: CO_2 Interactions: water	intra- & interspecific differences, plant growth, water relations, perennial & annual plants & seedlings, RAPD markers
L.Pachepsky B.Acock V.R.Reddy	Remote Sensing & Modeling Lab Beltsville, MD	Growth Chamber Greenhouse	tobacco, potato, soybean, tomata, cotton, peanut	Major: CO_2 Interactions: water, temperature	modeling, leaf anatomical and biochemical responses, photosynthesis & transpiration
J.Kiniry J. Williams	Grassland, Soil & Water Research Lab, Temple, TX	Field	C_4 grasses (switchgrass, big bluestem, sideoats grama, eastern gamagrass, blue grama), mesquite, juniper	Major: solar radiation	radiation use efficiency, canopy architecture, modeling
A.Heagle J.Miller E.Fiscus F.Booker S.Shafer R.Reinhert K.Burkey	Air Quality Research Program Raleigh, NC	Open-top Chamber	soybean, wheat, corn, cotton, alfalfa, peanut, sorghum	Major: ozone Interactions: CO_2 & UV	growth, physiology, species & functional group differences

Presenters/ Collaborators	Location	Experimental Environment	Major Species & Systems	Environmental Factors	Focus
S.Britz D.Krizek E. Lee J.M. Robinson	Climate Stress Lab, Beltsville, MD	Growth Chamber Greenhouse Open-top Chamber Exclusion Chamber	soybean, cucumber, lettuce, spinach	Major: UV-B or O_3 Interactions: UV-B, O_3, CO_2 & drought	assessment & mechanism
L.Allen J. Vu T. Sinclair J. Ray R. Serraj	Crops Genetics & Environ. Res. Unit Gainesville, FL	Greenhouses Chambers	sugarcane, soybean	Major: CO_2, temperature, water	growth, physiology, root nodulation, N_2 fixation

II. DELIVERABLE PRODUCTS FOR USERS

To address comments on how research of this group is delivering end products for users, the Ecosystem Dynamics Group was divided into two sub-groups, 1) Carbon Dioxide Enrichment and 2) Ozone/Radiation studies. Their respective presentations follow. In both groups, the issues are addressed in an outline form consisting of the *Impact* of a particular global change issue, *Actions/Options* being pursued, current *Status* of the research and *Reporting Units/Labs.*

CARBON DIOXIDE GROUP:

ISSUE: Temperature Variability & Moisture Availability

Impact:

Global warming and changes in precipitation will influence growth, quality, yield, and development of crops and rangelands. Distribution of crop production areas, rangeland types, and weed competition will be altered. Direct and indirect effects of increasing CO_2 will additionally affect all of the above both by itself and by interactions with other environmental variables.

Action or Option:

1. Increase accessibility of existing data bases.

2. Develop new knowledge bases and develop models encoding these knowledge bases. Run models and run assessments to project impacts on agriculture, including the determination of the effectiveness of proposed management or technological changes.

3. Identify traits associated with resistance to temperature and water stress which can be used by plant breeders.

4. Develop cultural practices which minimize adverse effects of changes in temperature and precipitation on agricultural productivity and on soil carbon storage. Specifically,
   a. develop alternative land use options,
   b. modify irrigation and fertilization strategies,
   c. alter planting time decisions to minimize stress risk, and
   d. develop sustainable grazing practices which consider increased temperature, altered precipitation and rising CO_2.

5. Evaluate pesticide use practices for greater effectiveness at higher temperatures and/or CO_2, as well as variable soil water.

6. Identify traits within important crop cultivars which could maximize economic yield under higher temperature and CO_2 and with changing precipitation.

7. Assess potential changes in weed/crop competition with respect to weed control costs and crop productivity.

Status of Research:

1. For some crops (soybean, wheat), large knowledge bases and models are currently available. For several others the knowledge, or at least the models, are not sufficiently developed.

2. Considerable historical information exists on temperature and water effects on crop productivity. However, knowledge of the effects of extreme water deficits and their interactions with increasing CO_2 and temperature need to be studied.

3. The direct and indirect effects of increased CO_2 concentrations and their interactions with other environmental variables need to be determined for several species.

Reporting Units/Labs:

Climate Stress Lab, Beltsville, MD
Crop Genetics & Environmental Research Unit, Gainsville, MD
Grassland Soil and Water Research Lab, Temple, TX
National Soil Dynamics Lab, Auburn, AL
Rangeland Resources Research Unit, Cheyenne, WY & Fort Collins, CO
Remote Sensing & Modeling Lab, Beltsville, MD
U.S. Water Conservation Lab, Phoenix, AZ

OZONE/RADIATION GROUP:

ISSUE: Tropospheric Ozone

Impact:

1. O_3 levels are double those of pre-industrial era, but it is not clear that they will continue to increase.

2. Ambient levels are above the threshold to reduce yields for some crops.

3. Effects depend on atmospheric CO_2. Conversely, CO_2 effects depend on tropospheric O_3 levels. This is a neglected area of study.

4. Effects of O_3 also depend on interactions with other stressors.

Actions/Options:

1. Identify mechanisms for resistance to O_3 and along with genetic diversity of responses, extend the knowledge base for distribution of sensitivity to O_3 among grasses, weeds and other species.

2. Determine the mechanistic basis for interactions between O_3 and other environmental factors, considering O_3 flux into leaves, availability of antioxidants, and responsivity of repair systems. Are lines that respond to CO_2 more sensitive to stress, including O_3?

3. Provide stress resistant lines by classical breeding and/or genetic engineering.

Status:

1. Initial results are available, but extensive work is required to complete most A/O (10 years?)

Reporting Units/Labs

Air Quality Research Unit, Raleigh, NC

Climate Stress Laboratory, Beltsville, MD

ISSUE: Solar Radiation - Quantity & Quality

Impact:

1. Solar radiation may be affected by changes in cloud cover associated with increases in atmospheric water vapor accompanying potential global warming. Both quantity (i.e., irradiance) and quality (the ratio of visible to infrared radiation) would be affected.

2. Significant reductions in stratospheric O_3 in recent years (based mainly on satellite measurements), have not been matched by consistent reports of increased ground-level UV-B radiation (i.e., radiation quality). A number of factors may contribute to this discrepancy, including tropospheric O_3 and other pollutants that absorbs UV as well as aerosols that scatter UV. Future changes in UV-B radiation are difficult to predict, but the potential remains for increases in UV-B. Cleaner air could increase UV transmission. Although production of illicit CFCs is reported by manufacturers to be on the decline, there are unconfirmed reports of increasing illicit CFC production around the world. Stratospheric cooling (already observed) is expected to accompany tropospheric warming

if the greenhouse effect increases. Lower stratospheric temperatures in conjunction with increased water vapor are hypothesized to lead to increased polar stratospheric clouds, the surfaces on which O_3 destruction takes place.

3. The potential for increased UV-B radiation to affect crops remains unclear, even in soybeans, the crop that has received the greatest scrutiny. The interpretation of data obtained from UV- supplemental lamps requires more attention (e.g., evaluation of spectral quality of light sources). The potential for ambient levels of UV to induce protection needs study. Dose response curves. Scaling growth chamber and greenhouse experiments to the field. Specific mechanisms (DNA damage, metabolic changes, developmental/morphological adaptations).

Action:

1. Extend exclusion studies using filters that transmit variable amounts of UV-B (simulating increases in stratospheric ozone) and compare to supplemental lighting systems that simulate decreases.

2. Evaluate more species and genetic lines and examine yield and product quality in physiologically-mature plants

3. Study mechanisms of protection and damage and relate to potential future changes in UV-B.

4. Evaluate interactions between UV-B and stress.

Status:

Initial results are available, but extensive work is required to complete most A/O (10 years?).

Reporting Units/Labs

Air Quality Research Unit, Raleigh, NC

Climate Stress Laboratory, Beltsville, MD

FACE Project Status: Wheat Productivity and Energy and Water Balances

Principal Scientists: Bruce A. Kimball, Gerard W. Wall, Robert L. LaMorte, Neal R. Adam, Paul J. Pinter, Jr., Francis S. Nakayama, Floyd J. Adamsen, Douglas J. Hunsaker

Cooperating Scientists: Steve Leavitt, Tom Thompson, Allen Matthias, Roy Rauschkolb, Andrew Webber, John Nagy, George Hendrey, Keith Lewin, and about 15 more.

ARS GCRP: Res. Areas:		Prog. Elements:		Objs:		Tasks:	
	I;		C;		1;		8
	I;		C;		2;		8
	I;		D;		1;		2

CRIS Number: 5344-11000-005-00D

Problem: Determine the effects of the increasing atmospheric CO_2 concentration and any concomitant climate change on the future productivity, physiology, carbon sequestration, and water use of crops.

Approach: Free-air CO_2 enrichment (FACE) at 550 μmol/mol was used to expose wheat crops growing in an open field to elevated CO_2, at ample and limiting levels of water (1992-94) and of soil nitrogen (1995-1997). Measurements were made of physiological processes, growth, yield, energy and water relations, and soil carbon sequestration.

Findings: In FACE wheat plots supplied with ample water, foliage temperatures increased by 0.6 and 1.1 °C at high and low N, respectively. At high N, evapotranspiration was consistently lower than that from ambient control plots, about 8% on the average, whereas at low N, evapotranspiration was reduced even more, about 16%, as determined by energy balance measurements. FACE increased soil CO_2 flux by 6 and 27% at the high and low N levels, respectively. The FACE treatment also enhanced whole-canopy daily carbon accumulation, as measured with canopy photosynthesis chambers, by 9% whereas the low N treatment reduced it 6%. At the same time photosynthesis of the upper leaves was enhanced 37% by FACE and reduced 24% by low N, with the marked differences between whole-canopy and upper-leaf responses apparently being caused by dramatic effects of N on canopy architecture. Biomass accumulation was 15-20% higher due to FACE at both high and low N for much of the season. However, at low N the increase due to FACE tended to decrease the last third of the season. Final grain yields increased about 15 and 12% due to FACE at high and low N, respectively.

Future Plans: First, analyses and reporting of the results from the 1995-7 FACE Wheat experiments will be completed. Then, as part of the NSF/DOE/NASA/USDA/EPA Joint Program on Interagency Terrestrial Ecology and Global Change ("TECO III"), the FACE Project will continue on sorghum in two replicate experiments in the 1998 and 1999 summer growing seasons. The interaction of elevated CO_2 and soil water supply on the growth, physiology, soil carbon sequestration, and water relations of this important C4 grass ecosystem will be studied.

Publications from 1996-1997:

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HUNSAKER, D.J., B.A. KIMBALL, P.J. PINTER JR., R.L. LAMORTE, and G.W. WALL. 1996. CO_2 enrichment and irrigation effects on wheat evapotranspiration in a free-air environment, Trans of the ASAE. 39(4):1345-1355.

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LEAVITT, S.W., E.A. PAUL, E. PENDALL, P.J. PINTER JR., and B.A. KIMBALL. 1997. Field variability of carbon isotopes in soil organic carbon. Nuclear Instruments and Methods in Physics Research B. 123:451-454.

Sour Orange Tree Project Status: Wood Density, Fruit Dry Weight and Total Productivity

Principal Scientists: Sherwood B. Idso, Bruce A. Kimball

ARS GCRP: Res. Areas:	I; Prog. Elements:	C; Objs:	1; Tasks:	8
	I;	C;	2;	8

CRIS Number: 5344-11000-005-00D

Problem: Determine the long-term effects of a 75% increase in the air's CO_2 concentration on the growth and development of trees.

Approach: In July 1987, eight 30-cm-tall sour orange tree (*Citrus aurantium* L.) seedlings were planted directly into the ground at Phoenix, Arizona. Four identically-vented, open-top, clear-plastic-wall chambers were then constructed around the young trees, which were grouped in pairs. CO_2 enrichment -- to 300 μmol/mol above ambient (400 μmol/mol) -- was begun in November 1987 to two of these chambers and has continued unabated since that time. Except for this differential CO_2 enrichment of the chamber air, all of the trees have been treated identically, being irrigated and fertilized as deemed appropriate for normal growth. Numerous measurements of a number of plant parameters have been made on the trees, some weekly, some monthly, and some annually. Results of our most recent findings are summarized below.

Findings: Based on detailed labor-intensive studies conducted on the trees at the conclusions of the second and third full years of the experiment, we developed a simple relationship between trunk cross-sectional area and total trunk plus branch volume. We have subsequently used this relationship to estimate the volume of new woody tissue produced by each tree over the course of each succeeding year. We have also harvested and weighed all fruit produced by each tree each year; and from these data we have demonstrated that the productivities of the CO_2-enriched trees have typically been about double those of the ambient-treatment trees over the entire course of the experiment, which is currently the longest such study ever to be conducted anywhere in the world.

In an attempt to make this comparison more precise, this past year we also determined the densities of a large number of 10-cm branch segments from each tree, as well as the percent dry matter contents of 200 randomly-selected oranges within each treatment. Preliminary results indicate that the wood of the CO_2-enriched trees is about 6% more dense than the wood of the trees growing in normal air, while the fractional dry matter content of the CO_2-enriched oranges is about 3% greater than that of the oranges produced on the ambient-treatment trees. In addition, there is only about half as much scatter in the wood density data of the CO_2-enriched trees, indicating that besides being stronger, the wood of the CO_2-enriched trees is also more uniform than the wood of the ambient-treatment trees, both of which characteristics are highly prized in the forest-products industry. And, of course, the CO_2-enriched trees produce much more of this higher-quality wood each year.

Future Plans: We hope to continue the sour orange tree experiment for as many more years as are needed for them to achieve the nearly steady yearly growth rates that are characteristic of full maturity.

Publications from 1996-1997:

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GLOBAL CHANGE AND BELOWGROUND PROCESSES IN AGRICULTURAL SYSTEMS

H. H. Rogers, S. A. Prior, H. A. Torbert, D. W. Reeves, R. L. Raper, D. C. Reicosky, D. E. Stott, **ARS**‖G. B. Runion, G. L. Mullins, **Auburn**‖R. J. Mitchell, **Jones Ecol. Res. Ctr.**‖W. A. Dugas, **Texas A & M**‖J. S. Amthor, **Oak Ridge**‖J. L. J. Houpis, **Southern Illinois**‖C. M. Peterson, **Northern Colorado**‖H. BassiriRad, **Illinois**‖ S. V. Krupa, **Minnesota**‖W. H. Schlesinger, **Duke**

CRIS: 6420-11000-001-00D

PROBLEM: The global environment is changing and it is evident from an incontestable data base that CO_2 within the atmosphere has risen substantially and, in all probability, will continue to rise. The most noted consequence, albeit uncertain, of this increase are predicted shifts in Earth's climate. Perhaps this high degree of uncertainty is the most important reason for in-depth exploration of the question. Regardless of the eventual outcome of the climate issue, vegetation will be directly affected by the increased concentration of atmospheric CO_2. This increase in CO_2 has led to many uncertainties associated with Earth systems. Concerns encompass indirect effects related to predicted shifts in climate and direct effects on the biosphere, mainly terrestrial plant systems, crops being a chief concern. Plant growth is often stimulated when CO_2 concentrations rise and the stimulation of root development immediately leads to hypotheses of shifts in rhizosphere microbiology and soil processes. Enhanced plant growth further suggests greater delivery of C to soil, and thus potentially more soil C storage. However, little research has focused on belowground responses in agricultural systems.

OBJECTIVES: Reduce uncertainty regarding: (1) the effects of rising atmospheric CO_2 concentrations on crop production and food security, and (2) the role of agronomic systems in the sequestration of atmospheric CO_2 as organic carbon in soils, as affected by tillage systems, crop rotations, and production practices. Specific objectives include the determination of CO_2-induced effects on belowground processes which affect crop productivity, soil properties, and carbon/nutrient cycling. Effects of rising CO_2 levels on root structure and function, and the interactions between crop roots, soil microorganisms, and soil organic carbon will also be documented.

FUTURE PLANS/APPROACH: We are in the initial stages of installing a new six year comparative study of a "conventional" tillage system without winter cover crops and a "sustainable" system with minimum tillage and winter cover crops. Crop rotations include grain sorghum (*Sorghum bicolor* L. Moench), soybean (*Glycine max* L. Merr.), wheat (*Triticum aestivum* L.) and crimson clover (*Trifolium incarnatum* L.)]; the soil is a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults). Work will take place at soil bin facilities of the ARS-USDA National Soil Dynamics Laboratory. There are three objectives: (1) Determine effects of elevated atmospheric CO_2 on plant roots (structure and function), rhizosphere microbiology (activity and populations), and soil properties (chemical and physical). (2) Quantify the cycling of carbon (including sequestration potential) and nutrients (including implications for groundwater quality) in CO_2-enriched agricultural systems. (3) Develop new methodologies for belowground research, with provision for assessment of atmospheric composition, temperature, and water, nutrient, and carbon dynamics.

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Runion, G.B., Entry, J.A., Prior, S.A., Mitchell, R.J., and Rogers, H.H. 1997. Effects of elevated atmospheric CO_2 and water stress on tissue chemistry and carbon allocation in longleaf pine seedlings. Tree Physiology. (In Review).

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Responses of Prairie Grasses to Defoliation, Nitrogen & CO_2 Enrichment
Rangeland Resources Research Unit: Ft. Collins & Cheyenne

Principal Scientists: JA Morgan, RH Skinner[1], GL Hutchinson[2], JD Hanson[1], JD Reeder & GS Schuman

ARS GCRP: Research Area I; Program Element C; Objective 2; Tasks 3-7 & 10.

CRIS Numbers: 5409-11210-001-00D

Problem: Most research into plant response to increasing atmospheric CO_2 concentrations has focused on cultivated, mostly C_3 species. Few studies have considered native ecosystems in which C_4 grasses are important components, and fewer yet in the context of how elevated CO_2 might interact with management practices. Knowledge of how elevated CO_2 concentrations may interact with plant physiology/ecology under different management practices will be necessary for formulating intelligent management alternatives as global change progresses.

Approach: In order to investigate how defoliation (grazing) interacts with plant response to CO_2 enrichment, two growth chamber studies were instigated. The first study was completed this past year, and evaluated how growth at two levels of CO_2 (350 and 700 $\mu L\ L^{-1}$) and two levels of N fertility affected re-growth and re-mobilization of C and N reserves in twenty days following defoliation in *Pascopyrum smithii* (C_3), *Bouteloua gracilis* (C_4), and *Medicago sativa* (C_3). A second study was begun this spring, and evaluates growth, resources partitioning, as well as system C and N cycling in 30-cm depth, 25 cm-diameter cores of soil/sod from the northern mixed prairie to one seasons growth at 350 and 700 $\mu L\ L^{-1}$ CO_2, two levels of N (un-fertilized and N fertilized), and two defoliation treatments (none and defoliation once in the early summer).

Findings: In the first experiment, re-growth of all three species was enhanced at the higher level of N fertility. Elevated CO_2 also enhanced regrowth of the two C_3 species, but inhibited re-growth in the C_4, *B. gracilis*. All three species were unable to convert total non-structural carbohydrates (TNC) into structural materials fast enough to keep up with the increased carbon supply at elevated CO_2, so TNC accumulated in above- and below-ground tissues. Carbohydrate concentrations were not simply related to re-growth, nor were there consistent correlations between carbohydrate or nitrogen remobilization and re-growth in the initial four days after defoliation. Data are still being collected in the second study, but visual observation indicates a strong growth enhancement in the mixed-grass prairie at the higher levels of N fertility and CO_2.

Future Plans: Two manuscripts have begun describing responses of the three species, one focusing on growth responses, the other on re-mobilization of C and N compounds. A third modeling manuscript will follow, examining how partitioning and re-growth of these species respond to the environment. The second growth chamber study is slated to run next summer (1998) to obtain two more complete replications of the experiment. Data analysis and interpretations will follow.

[1]Great Plains Systems and [2]Soil Plant-Nutrient Research Units, Ft. Collins, CO.

Publications: Skinner, RH, JA Morgan and JD Hanson. 1997. Nitrogen and CO_2 effects on remobilization of root and crown reserves for regrowth following defoliation. XVIII International Grassland Congress, pp 9.9 & 9.12, Winnipeg, Canada.

Carbon Uptake on the Shortgrass Prairie
Rangeland Resources Research Unit: Ft. Collins & Cheyenne

Principal Scientists: JA Morgan, DR LeCain, GE Schuman & JD Reeder

Cooperating Scientists: RH Hart

ARS GCRP: Research Area III; Program Element A; Objective 3; Task 3

CRIS Numbers: 5409-11210-001-00D

Problem: As atmospheric greenhouse gasses continue to increase and recent reports suggest climatic change may be underway, there is a critical need to understand how environment and management affect carbon fluxes and storage in grasslands. This information is required to understand how best to manage our rangelands for sustained productivity while protecting this resource from degradation. Knowledge of the capability of grasslands to assimilate and store carbon is also needed for understanding how these systems interact with the global carbon cycle.

Approach: Closed-chamber measurements of CO_2 assimilation rates (A) of meter square areas of short-grass steppe (SGS, Nunn, CO) and northern mixed-grass prairie (NMP, Cheyenne, WY) plus soil water, temperature, and vegetation cover have been measured for three years on heavily- and lightly-grazed pastures as well as on long-term exclosures. Bowen ratio/energy balance measurements of CO_2 and H_2O have also been made on an exclosed (CO) and lightly-grazed pasture (WY) to determine seasonal and diurnal flux rates.

Findings: Three seasons of measurement (1995-1997) revealed that grazing enhances early spring A in NMP due to earlier spring green-up compared to exclosures. As the growing season progressed, green leaf area and A increased in all pastures, but more so in the ungrazed exclosures, resulting in occasional higher A compared to grazed pastures. Seasonal differences in grazed and exclosed pastures in the SGS were not as simply related to green leaf area, but reflected differences in photosynthetic functional groups as well. A cool, wet spring in 1995 resulted in higher early-season A in the cool-season, C_3-species dominated exclosures, whereas the warm, dry spring of 1996/97 resulted in higher A in the warm-season, C_4-species dominated grazed pastures. Differences in A due to grazing in the SGS diminished by July. Grazing influenced A primarily through changes in species composition on the SGS, while grazing caused earlier spring green-up and improved A on the NMP. Bowen ratio measurements of A began in 1996, and a limited data set is currently being analyzed. Initial analyses show good correspondence between gas fluxes and light and precipitation events.

Future Plans: This is the final year for the chamber CER measurements. A manuscript will be written this winter and submitted in the spring to a journal. More effort will be spent in the following years on the Bowen Ratio measurements. We will take some limited paired comparisons between Bowen Ratio and chamber measurements to compare methodologies, and add cellular phone connections to the WY and CO stations to allow more frequent monitoring.

Publications:

DR LeCain, JA Morgan, GE Schuman, JD Reeder and RH Hart. 1997. Grazing affects canopies and carbon uptake differently in shortgrass steppe and northern mixed prairie. ASA Abstracts, Agronomy Meetings, Anaheim, CA.

Global Change in the Shortgrass Steppe: Experimentation & Modeling
Rangeland Resources Research Unit: Ft. Collins & Cheyenne

Principal Scientists: JA Morgan, HW Hunt[1], & DR LeCain

Cooperating Scientists: JJ Read & DX Chen[1]

ARS GCRP: Research Area I; Program Element C; Obj. 2; Tasks 3-8 & Obj. 3; Tasks 2,3.

CRIS Numbers: 5409-11210-001-00D

Problem: Plant species with the C_3 photosynthetic pathway are perceived to be most responsive to increased atmospheric CO_2 concentrations, so research has focused primarily on them and has neglected plants with the C_4 photosynthetic pathway. However, information from our group and a few others suggest that, under some conditions, C_4 species may exhibit substantial growth responses to rising CO_2 concentrations. The shortgrass steppe of eastern Colorado contains a mixture of both C_3 and C_4 grasses. Information on the physiological responses of shortgrass steppe photosynthetic functional groups and possible effects on their adaptability and competitiveness are needed to predict how elevated CO_2 will affect the ecology of this region.

Approach: Growth chamber and associated modeling experiments were completed that evaluated basic physiological responses of C_3 and C_4 grasses to elevated CO_2 and water. In the first study, photosynthesis, carbohydrate metabolism, water relations, plant growth and partitioning, and nutrient uptake were evaluated in *Pascopyrum smithii* (C_3) and *Bouteloua gracilis* (C_4) grown at two CO_2 levels and two water levels. In a second investigation, photosynthetic responses to CO_2 were investigated in six grass species from two of the three C_4 decarboxylation sub-types. We hypothesized that NAD-ME C_4 species, which are believed to be the least efficient C_4 sub-type, would respond more to CO_2 compared to the more efficient NADP-ME sub-type.

Findings: In the first experiment, leaf CO_2 assimilation, transpiration use efficiency, plant growth, and whole-plant water use efficiency of both species were greater at elevated CO_2, although responses were more pronounced for *P. smithii*. Declining soil water content with time was associated with an increased sequestering of total non-structural carbohydrates, storage carbohydrates and biomass in belowground organs of *P. smithii*, but not *B. gracilis*. Modeling exercises predicted growth and biomass partitioning responses of *P. smithii* and *B. gracilis* accurately based on their photosynthetic pathway and the balanced growth concept. In a second experiment, we found no evidence to support the notion that differences in growth or photosynthetic responses among six C_4 grass species relates to their particular decarboxylation sub-type. More importantly, we found no evidence that photosynthesis in any of the C_4 grasses was CO_2-saturated at present CO_2 concentrations under the conditions of the study.

Future Plans: Modeling exercises are proceeding with the photosynthesis and water relations data to determine how elevated CO_2 affects photosynthesis through its combined effects on water relations and plant metabolism. Further experiments are being considered to further evaluate C_4 photosynthetic and water relations responses to elevated CO_2 and temperature.

[1]Natural Resource Ecology Lab, Colorado State University, Ft. Collins, CO

Publications:

Chen, D.-X., H.W. Hunt, and J.A. Morgan. 1996. Responses of a C_3 and C_4 perennial grass to CO_2 enrichment and climate change: Comparison between model predictions and experimental data. Ecological Modeling 87:11-27.

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Hunt, H.W., J.A. Morgan, and J.J. Read. 1996. Simulating growth and partitioning in prairie grasses grown under different CO_2 and water regimes. GCTE & COST 619 Workshop "Interactions Between Elevated CO_2 and water in grassland, Davos, Switzerland. (Abstract)

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Read, J.J., J.A. Morgan, N.J. Chatterton, and P.A. Harrison. 1997. Gas exchange and carbohydrate and nitrogen concentrations in leaves of *Pascopyrum smithii* (C_3) and *Bouteloua gracilis* (C_4) at different carbon dioxide concentrations and temperatures. Ann. Bot. 79:197-206.

Causes and Consequence of Photosynthetic Acclimation to Elevated Carbon Dioxide

James A. Bunce, Richard C. Sicher and Lewis H. Ziska
Climate Stress Laboratory, Beltsville

CRIS Numbers: 1270-21000-015-00D

ARS Global Change Research Program, Research Area, Program Elements, Objective and Task: I Structure and Function, C Ecological Systems, Objective 1, Task 6

Problem: The stimulation of photosynthesis at elevated carbon dioxide generally seen in C3 plants often decreases after prolonged exposure to the higher carbon dioxide concentration. The timing and extent of the reduction is quite variable, greatly complicating efforts to predict photosynthesis as atmospheric carbon dioxide increases. In addition to reducing plant growth rate, photosynthetic acclimation could be involved in reducing stomatal conductance, which has consequences for plant water balance. Usually photosynthetic acclimation is associated with a reduction in activity of ribulose-bisphosphate carboxylase, a key photosynthetic enzyme, but the cause of the reduction is unknown, as are reasons for the variability in the reduction.

Approach:

A. Examine barley, corn, potato, sorghum, soybeans and wheat grown in the field at elevated carbon dioxide for photosynthetic acclimation, and determine its relationship to any stomatal acclimation.

B. Screen locally adapted soybean cultivars for differences in the amount of photosynthetic acclimation to elevated carbon dioxide.

C. Determine if chlorophyll fluorescence measurements are useful in characterizing the acclimation of photosynthesis to elevated carbon dioxide.

Findings:

A. Acclimation of photosynthesis was consistently found in wheat, barley and potato, occurred sporadically in soybean, and did not occur in sorghum or corn. All species except corn exhibited acclimation of stomatal conductance, with conductance lower for the same measurement conditions in plants grown at elevated CO2. There was no consistent relationship between stomatal and photosynthetic acclimation.

B. Significant differences among soybean cultivars in the amount of acclimation of photosynthesis to elevated CO2 were found under greenhouse conditions. The cultivars also differed in the stimulation of early vegetative growth by elevated CO2, but there was no clear relationship between the amount of photosynthetic

acclimation and the amount of stimulation of growth rate.

C. Chlorophyll fluorescence has not proven useful in characterizing the acclimation of photosynthesis to elevated CO_2 in wheat, barley, soybean or potatoes.

Plans:

Examine multiple successive plantings of soybeans for the occurrence of acclimation to elevated CO_2, and relate any acclimation to weather during leaf development. Analyze plant growth and source-sink balance during leaf development, and assess biochemical causes of acclimation. Examine a range of modern soybean cultivars for variation in photosynthetic acclimation to elevated CO_2, in the stimulation of vegetative growth by elevated CO_2, and the response of seed yield and quality to elevated CO_2.

Publications:

Bunce, J. A. 1997. Variation in growth stimulation by elevated carbon dioxide in seedlings of some C3 crop and weed species. Global Change Biol. 3: 61-66.

Sicher, R. C. and Bunce, J. A. 1997. Relationship of photosynthetic acclimation to changes of Rubisco activity in field-grown winter wheat and barley during growth in elevated carbon dioxide. Photosyn. Res. 52: 27-38.

Ziska, L. A. and Bunce, J. A. 1997. The role of temperature in determining the stimulation of CO_2 assimilation at elevated carbon dioxide concentration in soybean seedlings. Physiol. Plantar. 100: 126-132.

Responses of Plant Respiration to Increases in Carbon Dioxide and Temperature

James A. Bunce and Lewis H. Ziska
Climate Stress Laboratory, Beltsville

CRIS Numbers: 1270-21000-015-01T and 1270-21000-015-00D

ARS Global Change Research Program, Research Area, Program Elements, Objective and Task: I Structure and Function, C Ecological Systems, Objective 1, Task 7

Problem:

Respiration is a substantial component of plant and ecosystem carbon balance, and must be reliably predicted in crop simulation models as well as in ecosystem models. Respiration is a vital plant process and changes in respiration can both cause and reflect changes in plant growth rate. Respiration often responds directly to carbon dioxide concentration, and indirectly because of changes in growth rate or tissue composition. Respiration increases strongly with increasing temperature in the short-term, however acclimation may reduce the long-term increase. The interaction between carbon dioxide and temperature on respiration has not been adequately quantified.

Approach:

Relate respiration rates to photosynthetic rates and plant growth rates and analyze tissue composition to separate total respiration into the growth and maintenance respiration components. Determine the importance of direct and indirect effects of carbon dioxide on the observed rates of respiration. Determine the consequence to plant growth of a reduction in respiration rate induced by elevated carbon dioxide.

Findings:

In examining the kinetics of leaf respiration during the light-dark transition, we obtained no evidence in soybean that leaf respiration was greater in the light than in the dark. Root respiration increased when the shoot was illuminated, or when photosynthesis was increased by elevating CO2. However, the effect was quite small, and did not introduce an important error in the analysis of respiration from 24 h whole plant CO2 exchange. Previous whole plant data indicating that elevated CO2 reduced maintenance respiration can not be criticized on this basis. Acclimation of respiration to temperature occurs such that respiration at the growth temperature is nearly independent of growth temperature. Acclimation of respiration to an increase in temperature can be complete within a few hours in soybean leaves, but takes more than a day when temperature is decreased.

Plans:

Examine the importance of reduced respiration at elevated CO2 to plant growth by exposing plants to elevated CO2 only during the dark period, and measuring photosynthesis, respiration, leaf area expansion and growth rate. Further investigate the kinetics of the acclimation of respiration to temperature.

Publications:

Bunce, J. A. and Ziska, L. H. 1996. Responses of respiration to increases in carbon dioxide concentration and temperature in three soybean cultivars. Ann. Bot. 77: 507-514.

Scaling stomatal responses to CO_2 from the leaf to the field.

James A. Bunce
Climate Stress Laboratory, Beltsville

ARS GCRP Res. Area: I; Prog. Element: C; Obj: 3; Task: 1

CRIS: 1270-21000-015-00D

PROBLEM:

One of the primary effects of increasing atmospheric carbon dioxide concentration on plants is a reduction in stomatal conductance to water vapor. While this response is well documented for plants grown at the current carbon dioxide concentration, there is little information to indicate whether stomatal responses to environment are modified by long-term exposure to elevated carbon dioxide. It is recognized that because of various feedback systems, the relationship between decreased stomatal conductance and evapotranspiration at the field scale is complex. Because it has not been possible to expose a large enough area to elevated CO2 such that field-scale plant-atmospheric feedback systems operate realistically, a modelling approach is being pursued to scale from stomatal conductance to evapotranspiration from fields.

APPROACH:

Use a soil-vegetation-atmospheric boundary layer model to assess the net effect on field-scale evapotranspiration of observed changes in stomatal conductance and leaf area caused by growth at 1.5 and 2 x current ambient CO2 concentrations. For barley, wheat, potato and sorghum determine whether long-term exposure to elevated carbon dioxide in the field alters maximum stomatal conductance at the growth CO2, and, if so, whether this is caused by photosynthetic acclimation to elevated carbon dioxide.

FINDINGS:

Both stomatal and photosynthetic acclimation to elevated CO2 occurred in barley, wheat and potato in the field, and stomatal but not photosynthetic acclimation occurred in sorghum. Stomatal conductance was reduced after long-term exposure to elevated carbon dioxide compared to the short-term responses to elevated carbon dioxide found in plants developed at the current ambient CO2 concentration. The acclimation of photosynthesis resulted from reduced RuBisco protein content and activity per unit of leaf area in wheat and barley, which accompanied the reduction in total soluble protein content at elevated CO2. The degree of photosynthetic acclimation was greatest late in the growth cycle, but occurred even in early vegetative growth. In none of the species could the acclimation of stomatal conductance be attributed to photosynthetic acclimation by any known mechanism.

Relative changes in simulated field-scale evapotranspiration were only a small fraction of the relative changes in stomatal conductance observed at elevated CO2 in alfalfa, orchard grass, soybean and corn plants grown at ambient and elevated CO2 under field conditions. For example, reductions of 50% in conductance reduced evapotranspiration by less than 10%. The relative contributions of the many forms of feedback producing this result have been quantified. Most feedbacks occur within the canopy and the atmospheric surface layer, and would apply to even modest sized fields.

PLANS:

Measure stomatal responses to light, humidity and temperature in sorghum and potato grown at ambient and elevated CO2 in the field. Examine the relative control of stomatal conductance by root zone and by leaf water status.

PUBLICATIONS:

Bunce, J. A. 1996. Growth at elevated carbon dioxide concentration reduces hydraulic conductance in alfalfa and soybean. Global Change Biol. 2: 155-158.

Bunce, J. A. 1996. Does transpiration control stomatal responses to water vapour pressure deficit? Pl. Cell and Environ. 19: 131-135.

Carlson, T. N. and Bunce, J. A. 1996. Will a doubling of atmospheric carbon dioxide lead to an increase of a decrease in water consumption by crops? Ecol. Modelling 88: 241-246.

Bunce, J. A., Wilson, K. B. and Carlson, T. N. 1997. The effect of doubled CO2 on water use by alfalfa and orchard grass: simulating evapotranspiration using canopy conductance measurements. Global Change Biol. 3: 81-87.

Wilson, K. B. and Bunce, J. A. 1997. Effects of carbon dioxide concentration on the interactive effects of temperature and water vapour on stomatal conductance in soybean. Pl. Cell Environ. 20: 230-238.

Evaluating the Photosynthetic and Growth Stimulation of Selected C_4 Crops and Weeds at Elevated Carbon Dioxide.

Lewis H. Ziska and James A. Bunce
Climate Stress Laboratory, Beltsville

CRIS Numbers: 1270-21000-015-00D

ARS Global Change Research Program, Research Area, Program Elements, Objective and Task: I: Structure and Function, C: Ecological Systems, Objective 2, Task 4.

Problem:

Because of the different photosynthetic pathways, it is anticipated that C_4 plants should be saturated at the current atmospheric CO_2 concentration while C_3 plants will continue to respond photosynthetically to increased atmospheric carbon dioxide. However in examining reviews which document the average response of C_4 plants to a doubling of CO_2 concentration, it is clear that for a number of C_4 species, significant increases in both growth and photosynthesis have been observed. Although little effort has been done to separate improved water relations from a direct effect on photosynthesis, it seems unlikely that improved water relations can, in all cases, account for the response of C_4 species to elevated carbon dioxide. Given the importance of plants with the C_4 photosynthetic pathway both as crops and weeds, documentation of the potential photosynthetic and growth response to increases in atmospheric CO_2 seems essential.

Approach:

1. Quantify the photosynthetic and growth response of C_4 plants with a doubling of CO_2 concentration and to separate changes in water relations from a direct stimulation of photosynthesis.

2. Examine a range of C_4 crops and weed species to determine if differential responses to increasing CO_2 occur between groups.

Findings:

Measurements over a range of carbon dioxide concentrations indicated that photosynthesis was significantly stimulated in eight of the ten species between 380 and 690 ppm carbon dioxide. The mean photosynthetic stimulation among the six C_4 weed species was 19% which was significantly higher than the 10% mean stimulation for the four C_4 crop species. Measurements of leaf water potential demonstrated that the increase in photosynthesis could not be attributed to improved water status at elevated carbon dioxide. Biomass was significantly higher at elevated carbon dioxide in four of the weed species, but not in any of the crop species. Data from this study indicate that some C_4 plants may respond directly to increasing carbon dioxide concentrations, and in the case of some C_4 weeds, may show photosynthetic and growth

stimulation comparable to those of C_3 species.

Plans:

To determine the basis for stimulation of certain C_4 plants the following experiments are either being conducted or planned. (1) Determine potential changes in respiratory carbon flux with elevated CO_2 at night; (2) Compare the degree of photosynthetic and growth enhancement among C_4 plants which vary in the amount of bundle sheath CO_2 "leakiness"; (3) Compare the relative degree of C_4 type photosynthesis by comparing delta C^{13} values for mature and new leaves.

Publications:

Ziska, L.H. and Bunce, J.A. 1997 Influence of increasing carbon dioxide concentration on the photosynthetic and growth stimulation of selected C_4 crops and weeds. Photosynthesis Research (In Press).

Intraspecific Variability of Crop Productivity in Response to Increases in Carbon Dioxide.

Lewis H. Ziska and James A. Bunce
Climate Stress Laboratory, Beltsville

CRIS Numbers: 1270-21000-015-00D

ARS Global Change Research Program, Research Area, Program Elements, Objective and Task: I Structure and Function, C: Ecological Systems, Objective 1, Task 8.

Problem:

The stimulation of photosynthesis and growth for a given C3 crop species at elevated carbon dioxide concentrations may vary intra specifically. Intraspecific variation could be used to select for optimal cultivars which could maximize commercial productivity in a future high CO_2 and/or high temperature environment. Such information would be especially valuable for plant breeders in selecting lines within agronomically important species such as soybean, wheat and rice. To date, however, little work has focused on determining whether sufficient genetic variability exists so as to select for crop genotypes which could maximize productivity.

Approach:

Determine if sufficient intraspecific variation exists by screening six soybean cultivars for potential changes in productivity and growth in climate controlled greenhouses at ambient and twice ambient CO_2 concentrations. Relative growth rate to be determined by sequential harvest up to anthesis and yield to be determined by weight of dry seed per plant for a given cultivar.

Findings:

An examination of seed yield per plant for six soybean varieties which differed in morphology, and maturity group indicated a relative increase of seed yield at elevated CO_2 concentrations which ranged from 10 to 40%, suggesting that sufficient variability exists within soybean to select for lines which could maximize yield at future levels of CO_2. Increased seed yield was associated with increased pod number but not seeds per pod or average seed weight. There was a significant correlation between changes in specific leaf weight at elevated CO_2 and seed yield but not between changes in total plant weight, changes in relative growth weight, assimilate partitioning, or timing of flowering.

Plans:

Construct field-based CO_2 chambers for evaluation of productivity of whole soybean canopies in response to increased CO_2. Examine additional cultivars in the climate controlled greenhouses. Determine if the relative yield response to CO_2 is associated with the relative stimulation of photosynthesis and the occurrence of acclimation over time.

Publications:

Ziska, L.H. and Bunce, J. A. 1995 Growth and photosynthetic response of three soybean cultivars to simultaneous increases in growth temperature and CO_2. Physiol. Plant. 94:575-584.

Ziska, L.H., Manalo, P.A. and R. A. Ordonez 1996 Intraspecific variation in the response of rice (Oryza sativa L.) To increased CO_2 and temperature: Growth and yield response of 17 cultivars. J of Experimental Botany 47:1353-1359

Genetic variation in honey mesquite for water use efficiency and response to elevated CO_2

Principle Scientists: Rodney E. Pennington, Charles R. Tischler, H. Wayne Polley, Hyrum B. Johnson

ARS GCRP: Res. Area: I; Prog. Element: C; Obj.: 2; Tasks: 3, 7, Obj.:3; Task 2

CRIS Number: 6206-11210-002-00D

Problem: Research suggests that the invasive shrub honey mesquite (*Prosopis glandulosa*) will grow more rapidly and become more competitive on grasslands as atmospheric CO_2 concentration continues to rise. However, intraspecific genetic variation for response to CO_2 enrichment and related traits has not been explored. Increases in production and competitiveness at elevated atmospheric CO_2 may exceed expectations if genotypes that are highly responsive to CO_2 proliferate. Characterization of genetic variation in mesquite is complicated by the fact that genetic and environmental influences cannot be distinguished *in situ*.

Approach: Experiments were conducted on maternal half-sib families of mesquite sampled across the east-west precipitation gradient occupied by the species to 1) characterize intraspecific variation in growth response to CO_2 and 2) characterize intraspecific variation in physiological and morphological traits that may influence CO_2 response and the distribution of genotypes across the precipitation gradient. A primary focus has been on carbon isotope discrimination (CID), a physiological parameter that is strongly correlated (in the negative direction) with whole plant water use efficiency (WUE). Additional work has been devoted to developing a molecular assay based on RAPD PCR markers that will allow the characterization of genetic variation in CID *in situ*. This approach may obviate the need for time- and labor-intensive common garden experiments, and permit the examination of many more individual plants (genotypes) in the field.

Findings: (Genetic variation in CO_2 response, CID, and other traits). Significant within- and among- family genetic variation in CID was identified in seedlings derived from trees from central TX to south-central NM. For some species, higher WUE (lower CID) is associated with plants derived from the driest locations, however no such relationship was observed for mesquite. High WUE was more prevalent in seedlings derived from trees in the wettest location (central TX). Rankings of families based on mean CID value were stable across experiments conducted during two summers (1996 & 1997). In the first of these experiments, half-sib family response to CO_2 enrichment (measured as the percentage increase in mean seedling height at 700 ppm CO_2 compared to ambient CO_2) rose linearly with mean CID value. However, a second experiment, conducted with different families during a period when cloudy days were more prevalent, showed no such relationship. Individual plants (genotypes) with exceptionally high or low CID values were transplanted to a field nursery. DNA was isolated from each and will be used to identify RAPD markers that correlate with CID. Data analysis is continuing for a recently completed experiment to more fully characterize between-family differences in growth response to CO_2 and other physiological and morphological parameters as well as possible correlations between such differences and site of origin.

(RAPD markers). Methods were perfected for isolating DNA from woody legumes. The feasibility of using RAPD markers to distinguish mesquite genotypes was established and markers were used to characterize variation within the Prosopis genus. For *P. glandulosa*, initial results indicate that within- and between-population genetic variation is approximately equal suggesting that mesquite may be a "generalist" as opposed to a "specialist".

Future Plans: The focus now is upon screening collected DNAs for RAPD marker that correlate with CID (and therefore, WUE). Once identified, these markers will be utilized to characterize genetic variation for WUE in mesquite populations *in situ*. Work is continuing to determine relationships among WUE, biomass response to CO2, and other morphological and physiological parameters. In conjunction with Jim Kiniry a field nursery containing 240 plants characterized in experiments described above, will be closely monitored to identify genetic variation in developmental, morphological, and light interception characteristics.

Publications:

Pennington, R.E., C.R. Tischler, H.B. Johnson, H.W. Polley, D.A. Brown and H.S. Mayeux. 1997. Genetic variation among selected mesquite populations in the Southwest: Characterization by RAPD PCR. Abstracts, 50th Annual Meeting of the Society for Range Management, p. 79.

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Plants and Water: Impacts of Rising Atmospheric CO_2 Concentration

Principle Scientists: H. Wayne Polley, Hyrum B. Johnson, Charles R. Tischler

ARS GCRP: Res. Area: I; Prog. Element: C; Obj.: 2; Tasks: 3, 7; Obj.: 3; Task 2

CRIS Number: 6206-11210-002-00D

Problem: Water availability exerts a dominant climatic control on the species composition of rangeland vegetation. The relationship of species composition to water availability may change, however, if the global increase in atmospheric CO_2 concentration (1) improves plant survival of water deficit or (2) reduces canopy transpiration rates and the rate and extent of soil water depletion.

Approach: Two experiments with rangeland species were conducted to investigate these possibilities. 1. Effects of CO_2 enrichment on survival of water deficit and traits that can contribute to the postponement or tolerance of plant dehydration were measured in seedlings of the invasive shrub honey mesquite (*Prosopis glandulosa*). Seedlings grown at the current and two elevated CO_2 concentrations were exposed to similar rates of soil water depletion. 2. Effects of CO_2 enrichment on whole-plant transpiration of two perennial C_3 species, bluebunch wheatgrass (*Pseudoroegneria spicata*) and threadleaf snakeweed (*Gutierrezia microcephala*), were measured during a second experiment. Transpiration is usually tightly correlated with plant nitrogen (N) content or concentration, so CO_2 effects on plant water use were studied by analyzing transpiration as the product of the amount of N acquired by plants and the ratio of transpiration to N acquisition.

Findings: (Plant survival of water deficit). Increasing atmospheric CO_2 concentration from the current concentration to near 700 and 1050 parts per million (ppm) more than doubled percentage survival of mesquite seedlings from which water was withheld for 65 days. Seedlings grown at elevated CO_2 had a greater root biomass and a higher ratio of lateral root to total root biomass than those grown at the ambient CO_2 concentration, but also shed more leaves and retained smaller leaves than counterparts at the current CO_2 concentration. Together, these changes reduced transpiration per unit leaf area at elevated CO_2 and apparently contributed to a slight increase in xylem pressure potentials of seedlings at the highest CO_2 concentration. Mesquite, like many other species, is most vulnerable to drought during the seedling stage. By increasing seedling survival of water deficit, rising CO_2 concentration could increase the abundance of mesquite on rangelands where low water availability currently limits its establishment.

(Whole-plant transpiration). Transpiration rarely declines by the same fraction as stomatal conductance at elevated CO_2. Compensatory changes at the leaf through canopy scales limit effects of stomatal closure on whole-plant transpiration. One of these compensating effects is an increase in leaf area. On many rangelands, however, leaf production is limited by low N availability. The extent to which increasing leaf area offsets lower transpiration per unit area in these systems will depend on the response of plant N acquisition to CO_2 concentration.

Transpiration is also influenced by how plant use acquired N, and need not scale proportionally with plant N as CO_2 rises if plants vary their use of water relative to N as predicted by theory. Elevating CO_2 concentration by 80% reduced whole-plant transpiration of bluebunch wheatgrass and threadleaf snakeweed plants by 26% during the first year of growth. Contrary to expectation, effects of CO_2 enrichment on transpiration were independent of N availability treatments that produced 4 fold differences in biomass. The decrease in transpiration at high CO_2 reflected both lower N acquisition and lesser use of water relative to N. The two species, by contrast, acquired similar amounts of N, but differed greatly in the ratio of transpiration to plant N. Results indicate that an improved understanding of plant N dynamics will be required to predict transpiration in a CO_2-rich world.

Future Plans: Whether beneficial effects CO_2 enrichment on plant water relations will be expressed equally or differentially among species and genotypes within species has implications for the pattern of species change expected on rangelands during the next century. Effects of CO_2 enrichment on survival of soil water deficit will be measured in different woody species and different maternal families of the shrub mesquite to address this question.

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Seedling Responses to Elevated CO_2. Intra- and Interspecific Differences.

Principle Scientists: Charles Tischler, H. Wayne Polley, Hyrum B. Johnson and Rod Pennington

ARS GCRP: Res. Area: I; Prog. Element: C; Obj.: 2; Tasks: 3, 7, Obj. :3; Task 2

CRIS Number: 6206-11210-002-00D

Problem: Effects of elevated CO_2 on early seedling growth have not been extensively studied. Reports in the literature suggest that seed mass is inversely related to speed of seedling response to elevated CO_2 (faster response associated with lower seed mass). Most reports published to date do not allow meaningful comparisons because of differences in developmental morphologies of the species studied. Also, possible intraspecific differences in seedling response to elevated CO_2 are poorly documented.

Approach: An experiment was conducted to address the question of whether speed of seedling response to elevated CO_2 is a function of seed mass. We utilized five epigeal C_3 species differing by roughly a factor of 20 in seed mass. These were cotton (*Gossypium hirsutum* var. Coker 317, 0.12-0.13 g), bagpod sesbania (*Sesbania vesicaria*, 0.23-0.26 g), mesquite (*Prosopis glandulosa*, 0.041-0.048 g), cucumber (*Cucumis sativus* L. cv. Straight-8, 0.026-0.030 g), and hemp sesbania (*Sesbania exultata*, 0.012-0.013 g). Seedling dry mass was measured at emergence, and on days 3, 6, 10, 13, and 16.

To address the question of whether intraspecific differences exist in seedling response to elevated CO_2, we grew 16 half-sib families of mesquite at 365 and 700 uL L^{-1} CO_2, and determined biomass and leaf area at 5, 10, 15, 20, and 25 days after emergence. Because of initial differences in seedling masses, the sequenced samplings were necessary to allow determination of relative growth rate at identical plant masses. Detailed leaf area measurements were also made to allow determination of other plant growth parameters. The half-sib families utilized in this experiment were collected across a precipitation gradient ranging from 34 to 8 inches of yearly rainfall.

Findings: (Interspecific response). By three days after emergence, seedling dry mass was significantly higher at 700 than at 365 uL L^{-1} CO_2 for each of the five species studied. Hemp sesbania and mesquite exhibited the greatest relative stimulation in growth by elevated CO_2 (percent increase in dry matter at elevated vs. ambient CO_2), while cucumber exhibited the greatest absolute stimulation in growth (accumulation of dry matter). These results suggest that positive responses to elevated CO_2 in seedlings may occur much earlier than indicated in the literature. The results also demonstrate that within the range of seed masses used in these experiments, there is no apparent relationship between seed mass and rapidity of response to elevated CO_2. Total biomass accumulation for the first sixteen days of growth appeared more related to maximum cotyledonary leaf area than to seed mass.

(Intraspecific response). Data analysis is being completed for this experiment. Leaf samples will also be analyzed for carbon isotope discrimination, to augment existing data relating carbon isotope discrimination to precipitation at the collection site.

Future Plans: The interspecific CO_2 response work will be expanded to include hypogeal species of a range of seed mass. Hypogeal species will include economically important legumes as well as guajillo (*Acacia berlandieri*) and cat claw acacia (*Acacia greggii*), two invasive shrub species. We will determine the earliest time at which positive responses to elevated CO_2 are evident in these species, and make comparisons with appropriate epigeal species of similar seed mass. Other planned work includes documenting relationships between seed size and depth of root penetration in deep shade. The objective of this work is to determine maximum possible rooting depth powered by only seed reserves. This information is needed to develop a body of knowledge adequate to initiate cooperative modeling work describing effects of CO_2 on invasiveness of C_3 species.

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Annual report

Strategic plan Issue:

Leaf anatomical and biochemical responses to global change factors: CO_2 concentration, temperature and soil water availability, and their effects on photosynthesis and transpiration

L.B.Pachepsky, B. Acock, V.R.Reddy
USDA, ARS, Remote Sensing and Modeling Lab., Beltsville, MD 20705

CRIS: 1270-66000-013-00D

PROBLEM:

The environmental factors that are expected to change in future as the global climate changes, all have pronounced effects on agricultural crops. Crop photosynthesis and transpiration are shown to be affected by changes in atmospheric CO_2 concentration, temperature, and water supply. However, the mechanisms by which these factors affect plants, and their interactions, are still not completely understood. Relative contributions of changes in photosynthetic rate and transpiration rate differ from one crop to another. These effects occur at the leaf level, where anatomical and biochemical changes control the diffusion of CO_2 and water vapor and thus the rates of photosynthesis and transpiration. Some authors attribute the observed changes in photosynthetic and transpiration rates primarily to stomatal regulation. However, our studies with 2DLEAF, a detailed two-dimensional model of leaf gas exchange show that stomatal aperture drastically affects transpiration rate when it decreases from fully open to 10% open, but it affects photosynthetic rate by no more than 15-20%.
Published experiments show that different species of crop plants use different strategies of adaptation to changed climatic conditions. Some species (e.g. soybean) change their leaf anatomy, while others (e.g. tomato) do not. Some species (e.g. cotton) change their chlorophyll content. The kinetic properties of Rubisco are known to change for a number of species, when [CO_2] and temperature change. All these findings imply that plants differ in how leaf gas diffusion and assimilation will change as global climate change progresses. Understanding which component of gas exchange is affected when external conditions change would allow us to significantly increase the precision of our predictions about the effects of global climate change on crop growth. It would also provide useful indicators for breeding more efficient crop varieties for future environments.

APPROACH:

We have collected experimental data on (1) leaf gas exchange, (2) leaf anatomy , and (3) biochemical characteristics, for leaves of several species, growing in various [CO_2], temperature and water conditions, in greenhouse and controlled-environment plant growth chambers. For tobacco and potato plants, the data for transgenic plants were also used in the analysis. This approach turned out to be especially effective. Photographs or drawings of leaf cross-sections were analyzed with SigmaScan software, and schematized for the 2DLEAF model. 2DLEAF has been parameterized, then used to quantitatively separate the contributions of the physical and biochemical components to the observed changes in photosynthesis and transpiration. This in turn enabled us to make reliable quantitative predictions of photosynthesis and transpiration rates for these crops in every possible scenario of global change. The 2DLEAF model has been developed and used for soybeans, tomato, tobacco, cotton, potato, and peanut leaves.

FINGINGS:

Anatomical, stomatal, and biochemical components of differences in photosynthesis and transpiration of wild-type and transgenic (expressing yeast-derived invertase targeted to the

vacuole tobacco and sucrose transport antisense potato) leaves grown in different light, relative humidity, and temperature conditions were quantitatively estimated.

Mechanisms of stomatal regulation for cotton leaves on the abaxial and adaxial sides were studied with the 2DLEAF model for Pima cotton at different, very high among them, temperature values in field conditions.

For the first time, parameters for a leaf boundary layer have been determined using the transpiration data for cv. Desiree and transgenic (sucrose transport antisense) potato leaves grown in different environmental conditions.

A combination of the molecular genetic methods with the methods of mathematical modeling was found to be very efficient way that allows to deeper understand the mechanisms of plant adaptation to the changing environment, that was not possible otherwise.

FUTURE PLANS:

The work will be continued during 1998. We have available the experimental data for wild-type and transgenic plants of several species. In transgenic plants various enzymes of the Calvin cycle have been targeted. We also have the data for plants with changing stomatal density that is expected to be different the future. These data will allow us to study the reaction of different enzymes in the assimilation process to changed environmental conditions.

PUBLICATIONS:

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ABSTRACT

Title: Development of crop management models to simulate possible future climates and hydrologic regimes.

Principal Scientists: **Jim Kiniry**

Cooperating Scientists: **J.R. Williams**

ARS GCRP Res. Area I; Prog. Element A: Objective:1; Task 4.

CRIS Numbers: 6206-13610-001-00D

Problem: Prediction of crop responses to climate changes, especially rainfall and temperature, depends on realistic crop simulations. Texas represents an area of extremes in temperature, relative humidity, and soil types. Many possible future scenarios for the Midwest are similar to the present climates experienced across Texas. Thus, Texas is ideal for testing simulation models for future climates.

Approach and Findings: We are studying two important systems for responses to climate. The first is row cropping of corn and sorghum. The other involves C4 grass systems, both with and without brush competition. We tested ALMANAC with corn and sorghum at four irrigated and five dryland sites in TX. These vary from warm humid locations in the Rio Grande valley and near the Gulf of Mexico to low humidity, high evaporative demand sites in northern TX and the High Plains. The model reasonably simulated grain yields of corn and sorghum at these diverse sites. These data sets and the model and parameters are available to users to aid in development of additional data sets at other locations.

Work with C4 grasses, mesquite and eastern red cedar involved the development of parameters for leaf area index, radiation use efficiency, and partitioning. Three years of field results with the two woody species indicates conservative RUE values of 1.62 g per MJ intercepted PAR for mesquite and 1.60 for cedar. After four years, LAI values were 1.25 for mesquite and 1.16 for cedar. Light extinction coefficients were 0.34 for mesquite and 0.37 for cedar. These values will greatly improve our ability to simulate grass/brush competition with ALMANAC. Our results in the field at Temple in three years with C4 grasses have shown a wide range of RUE values. Switchgrass had the highest RUE, sideoats grama the lowest, and big bluestem and eastern gamagrass intermediate values. Gas exchange measurements at representative heights in the leaf canopy initially showed no relationship between CER and RUE for these species. After stratifying each leaf canopy into ten layers, and using the CER light response functions and Beer's law with appropriate extinction coefficients, we found a strong relationship between whole canopy CER and RUE. We also studied potential rooting depth, partitioning to the roots, and increases in soil carbon. These values along with the LAI values and light extinction coefficients will greatly improve our ability to simulate these important grass species. Some of these parameters have already been incorporated into ALMANAC as shown in a multilocation validation study across Texas with switchgrass (Kiniry et al., 1996.).

Future Plans: Our work continues on parameter improvement with additional C4 grass species and mesquite and juniper.

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Global Change and Air Pollution: Effects of Atmospheric Composition on Crop Systems

Joseph E. Miller, Allen S. Heagle, Edwin L. Fiscus, Fitz L. Booker,
Steven R. Shafer, Chanatal. D. Reid, Richard A Reinert, and Kent O. Burkey
Air Quality Plant Growth and Development Research
USDA-ARS, North Carolina State Univ.
1509 Varsity Drive
Raleigh, NC 27606

CRIS Number: 6645-11000-004-00D

Problem

Many studies indicate that elevated CO_2 concentrations can increase crop yield, and estimates of future world food production are based partly on such studies. Conversely, tropospheric O_3 significantly reduces agricultural productivity in many regions of the U.S. Our recent research on the combined effects of elevated CO_2 and O_3 on soybean, cotton, and clover shows that the promotion of growth and yield by CO_2-enrichment can be attributed in part to the alleviation of damage from tropospheric O_3. Plants grown in clean (charcoal-filtered air) were much less stimulated by elevated CO_2 than plants grown in nonfiltered ambient air or in nonfiltered air with added O_3. The majority of studies of elevated CO_2 effects on plants have been done without the knowledge or control of O_3 concentrations during the experiments. Moreover, the impact of O_3 and/or CO_2 on pests and pathogens of crop plants remains largely unknown. Clearly, the effects of elevated CO_2 are mediated by O_3, but the interaction has yet to be fully evaluated. This has important implications for our understanding of plant productivity responses to elevated CO_2 and for our ability to predict and adapt to changes in the future.

Approach

Experiments are performed mostly in open-top field chambers where plants are exposed from emergence to maturity to a wide range of O_3 and CO_2 concentrations. Cotton was grown with three levels of urea to provide low, medium, and high N levels. Essex soybean was used to determine effects of diurnal duration of CO_2 enrichment and rooting environment on plant response to elevated CO_2. Essex soybean was also used to determine whether CO_2-induced amelioration of O_3 stress is due to: 1) exclusion of O_3 from the leaf interior by CO_2-induced partial stomatal closure; 2) enhanced resistance of the plants to O_3 from biochemical changes that may allow for repair of O_3 injury or enhanced detoxification of O_3; or, 3) a combination of these. In other field studies, effects of seasonal exposure to elevated CO_2 and O_3 were tested on three rice varieties and eight cultivars of winter wheat. Ten cultivars of Irish potato were screened for relative sensitivity to O_3-induced foliar injury and yield loss, and seven lines of snapbean that express a wide range of O_3 sensitivity were compared to determine the role of antioxidants in O_3 tolerance.

Findings

Increasing O_3 concentrations injured cotton plants and suppressed yield. Total soluble phenolics and condensed tannins in leaves were doubled by elevated CO_2 and low N. Positive effects of CO_2 enrichment on cotton yield were greater for plants stressed by O_3 than for nonstressed plants. The nature of this CO_2 x O_3 interaction was similar at all N levels.

Enrichment durations of 12 and 24 h d^{-1} caused similar growth and yield enhancement of soybean. There was no evidence of significant differences in proportional yield response to CO_2 between soybean plants in pots and in the ground. Measures of diurnal pools of the substrate ribulose-bisphosphate (RuBP) in soybean showed that RuBP concentrations increased through the day from dawn to mid-afternoon in all treatments except charcoal-filtered air at elevated CO_2, which peaked mid-morning. During reproductive growth, a decrease in Rubisco capacity concurrent with an increase in saturating C_i suggests that RuBP regeneration was increasing while Rubisco capacity was being down regulated by both elevated CO_2 and O_3. Midday O_3 flux calculations suggest a seasonal mean threshold for soybean yield loss in the range of 20 to 30 nmol m^{-2} s^{-1}.

Two of three O_3- sensitive snap bean lines contained significantly lower levels of glutathione, identifying it as a metabolite for further testing.

Data are being analyzed for experiments to determine mechanisms for CO_2 amelioration of O_3 stress of soybean and for the effects of CO_2 x O_3 mixtures on winter wheat and rice.

Future Plans

An O_3-sensitive and an O_3-resistant winter wheat cultivar were selected for a wheat experiment to begin in October 1997. An experiment to determine mechanisms of CO_2 amelioration of O_3 stress in soybean will be repeated in 1998. An O_3-sensitive (Norland) and an O_3-resistant (Superior) potato cultivar were selected for greenhouse and field experiments to determine if O_3 stress and CO_2 affect feeding, development rates and reproduction of the Colorado potato beetle. Experiments with snap bean and rice will continue.

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Amelioration of Acute Environmental Stress Thru Adaptation to Atmospheric and Edaphic Conditions

Principle Scientists: Steven J. Britz, Donald T. Krizek, Edward H. Lee, and J. Michael Robinson

ARS GCRP: Taxonomy TBD

CRIS Number: 1270-11210-005-00D

Problem: Crops are exposed to a range of different long-term and short-term environmental stressors. Interactions between such stresses are poorly characterized. In addition, elevated atmospheric CO_2 may ameliorate negative effects of environmental stress. The basis for these effects is also poorly understood.

Approach: Determine molecular and biochemical responses of crops to single and multiple chronic and acute environmental stresses in relation to elevated atmospheric CO_2. Experiments are conducted in controlled environments or open-top chambers in the field

Findings: Both ambient UV-B and UV-A radiation inhibited early growth in a number of crops (cucumber, spinach, soybean, and red lettuce). These results suggest that plants may not be adapted to current levels of UV and that the potential for increased UV radiation to cause damage needs more consideration. However, it is not clear whether UV effects are saturated at ambient exposures or will continue to increase with elevated levels of UV-B radiation. Responses to ambient UV-B were not always the same as responses to enhanced UV-B in controlled environments, indicating that caution should be used in interpreting experiments with supplemental UV lamps. Detailed photobiological experiments indicated that multiple UV photoresponses may take place simultaneously within a single organ. Anthocyanin levels were elevated by UV radiation in red lettuce, indicating that UV may be important for product quality.

The significance of ascorbic acid for the resistance of crops to tropospheric ozone was examined by comparing two lines differing in sensitivity to ozone. Ratios of ascorbate to dehydroascorbate were significantly lower in the sensitive line, consistent with the importance of high levels of reduced ascorbic acid as a factor in protection against ozone damage. Photosynthesis may play an important role in this process, since ascorbic acid is derived directly from glucose. In other experiments, the antiozonant compound EDU (ethylene diurea) was used to show that tropospheric ozone and UV-B may differ in the mechanisms by which they induce damage. EDU protected against damage from ozone (and also elevated soil manganese), but not against UV-B exposure. Fluorescence imaging techniques were applied to determine rapid responses to environmental stress (ozone, UV radiation).

Future Plans: Effects of photosynthesis and elevated CO_2 on specific processes related to environmental stress will be examined. In addition, interactions between stress factors will be investigated more intensively. Technology to study environmental stress in controlled environments will be developed and applied.

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Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Response of Sugarcane to Carbon Dioxide and Temperature

Principal Scientists: L.H. Allen, Jr. and J.C.V. Vu, Crop Genetics and Environmental Research Unit, Gainesville, Florida

Cooperating Scientists: T.R. Sinclair and J.D. Ray, ARS (and Sara Clendenin, ARS summer student Research Apprentice)

ARS GCRP CRIS Number: 6615-11000-004-00D **Date**: 22 September 1997

Problem: Rising carbon dioxide and other greenhouse-effect gases will change crop productivity through (a) photosynthetic response (the CO_2 fertilization effect) and (b) other plant growth responses to anticipated global warming (temperature effects) and changes in precipitation soil water availability). Research is required to quantify these productivity changes, and to identify management and genetic adaptations to ameliorate potential negative impacts.

Approach: On this subproject, studies are being conducted in 27.4-m X 4.3-m temperature-gradient greenhouses. These greenhouses provide four 5.5-m experimental zones along the length with differences maintained at 1.5° C steps above ambient by a combination of heaters, solar radiation, and computer-controlled ventilation fans. Temperature x CO_2 treatments are provided by paired CO_2-enriched and ambient-CO_2 greenhouses. Each temperature zone contained 8 vats containing 4 sugarcane cultivars, for a total of 32 vats per greenhouse. Half of the vats were filled with mineral soil and half with organic soil, and half of these have water tables that were set to 23 cm. The treatments are CO_2 (360 and 700 PPM), temperature (baseline, +1.5, +3.0, and +4.5° C), soil type (mineral vs. organic), water table (23 cm vs. 60- cm drained profile), imposed on four cultivars (CP72-2086, CP73-1547, CP88-1508, and CP80-2086).

Sugarcane seed pieces were planted on January 13, 1997 in a greenhouse seedbed, and vegetatively germinated plants were transplanted into the experimental greenhouses on March 21, 1997. Leaf photosynthetic rate measurements were made just prior to the first harvest in late June. Selected harvests were conducted in late June and early July 1997. Leaf samples were taken and preserved in liquid nitrogen for later determination of rubisco, PEP carboxylase, and SPS. Measurements on main stems were: number of green leaves per plant, leaf area, leaf fresh weight, leaf dry weight, mainstem length, mainstem fresh weight, mainstem dry weight, juice volume, hydrometer readings of juice soluble solids, and Brix determinations. Next, above-ground components of all plants were harvested and total fresh weight measured. Total fresh weight of mainstems harvested previously were added to these totals. Then, the number of tillers (large, dead, and total) were counted.

Doubled carbon dioxide concentration increased the following components of plant growth: Leaf number = 7%; Leaf area = 15%; Leaf fresh weight = 13%; Leaf dry weight = 8%; Mainstem length = 32%; Mainstem fresh weight = 31%; Mainstem dry weight = 23%; Juice volume = 40%; Total fresh weight = 25%; SubTotal dry weight = 19%; Juice dry weight = 36%; Total dry weight = 21%.

Total fresh weight increase due to elevated carbon dioxide determined from the whole-crop harvest was somewhat less at 16%.

Increasing temperatures caused a slight downward trend in sugarcane yield regardless of CO_2 treatment.

Fresh weight of sugarcane grown in mineral soil was about 27% greater than in organic soil; however, this effect was due to higher nitrogen fertilization of the mineral soil. In the peat soil of this study, mineralization of organic soil did not provide sufficient nitrogen.

Water table treatments were not implemented soon enough to have any effect. The ratoon crop has been re-established, and water table effects will be determined on the second crop.

Cultivar yields were: CP 73-1547 > CP 80-1827 > CP 88-1508 > CP 72-2086.

The number of tillers per plant was higher in the doubled CO_2 treatment.

Potential impact of findings on science and users: The results show that rising CO_2 may benefit sugarcane production more than the anticipated 10% increase for a doubling of carbon dioxide for a C_4 species. The scientific challenge will then be to determine the physiological reason for this yield promotion by elevated CO_2. The apparent increase in dry weight, fresh weight, and juice should lead to greater yields and perhaps an earlier harvest period as CO_2 continues to rise.

Future Plans: We plan to continue this subproject for at least 2 years, and obtain ratoon sugarcane harvests late in 1997 and twice in 1998. We plan to make detailed investigations of the root systems of the four cultivars to determine if there are any differences in survival and growth in flooded conditions. We have built an apparatus to measure the rate of transport of oxygen from shoot to roots, and plan to determine if there are any cultivar differences.

Publications: (June 1996- September 1997). None for this subproject.

Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Acclimation of Leaf Photosynthesis to Elevated Carbon Dioxide

Principal Scientists: L.H. Allen, Jr. and J.C.V. Vu, Crop Genetics and Environmental Research, Gainesville, Florida

Cooperating Scientists: R.W. Gesch, K.J. Boote, J.T. Baker, A.H. Pennanen, and G. Bowes, University of Florida

ARS GCRP CRIS Number: 6615-11000-004-00D **Date:** 22 September 1997

Problem: Rising carbon dioxide and other greenhouse-effect gases will change crop productivity through (a) photosynthetic acclimation to the CO_2 fertilization effect and (b) other plant growth responses to anticipated global warming and changes in precipitation. Research is required to quantify these changes in photosynthetic rates and to determine the genetic bases for the physiological mechanisms.

Approach: Experiments are conducted in controlled-environment, Soil-Plant-Atmosphere Research (SPAR) chambers. SPAR chambers control CO_2 concentration, air temperature, dewpoint temperature, and soil water conditions in natural sunlight with large rooting volume.

Findings: Rice. Experiments in SPAR chambers showed that methane emissions in paddy-culture were greatly increased by elevated CO_2. However, watertable drawdown to the point of drought during panicle initiation drastically reduced methane effluxes without causing a yield reduction, regardless of CO_2 exposure level. Drought during anthesis did cause a yield reduction. We conclude that carefully managed watertable drawdowns should result in sharp decreases in methane emissions with no loss of productivity. Forages. Experiments with a C-4 grass (Bahiagrass) and a C-3 forage legume (Rhizoma peanut) in temperature-gradient greenhouses showed little response of photosynthesis and growth, partitioning, and carbon sequestration across a range of 4.5°C above ambient. Doubled CO_2 (350 to 700 μmol mol^{-1}) increased growth of rhizoma peanut and bahiagrass about 30% and 10%, respectively.

Future Plans: (1) Conduct studies on photosynthetic acclimation of rice leaves and canopies to elevated CO_2 and N fertilization. The objectives are to determine the effect of photoassimilate sources and sinks on leaf rubisco limitations and on RuBP regeneration capacity under a relatively low N and very high N fertility regime. The N factor must be considered because our early studies on soybean (N-fixing legume) showed no downregulation of photosynthesis or decrease in rubisco protein, whereas rice showed both downregulation and decrease of rubisco at a common level of N fertilization. (2) Continue study of CO_2 and temperature effects on photosynthesis, growth, and plant and soil carbon sequestration of 2 forages.

Publications: (June 1996 - September 1997).

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Vu J.C.V., L.H. Allen, Jr., G. Bowes, and K.J. Boote. 1997. Kinetic properties of rubisco in rice and soybean grown under elevated CO_2, supraoptimal temperature, and drought. Plant Physiol. 114:S-1092(p.216-217) (Abstract).

Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Carbon Balance and Growth Adaptation of Contrasting C_3 and C_4 Perennial Forage Species to Increased CO_2 and Temperature

Principal Scientists: L.H. Allen, Jr. and T.R. Sinclair, Gainesville, Florida

Cooperating Scientists: K.J. Boote and L.E. Sollenberger

ARS GCRP CRIS Number: 6615-11000-004-00D & -12210-001-00D **Date:** 22 Sept. 1997

Problem: Rising carbon dioxide is expected to affect C_3 and C_4 species differently, and might affect legumes differently from nonlegumes. Little work has been conducted on tropical/subtropical grassland species. Therefore, two contrasting perennial species, a C_3 legume, rhizomous perennial peanut (*Arachis glabrata* Benth.), and a C_4 stoloniferous graminoid, bahiagrass (*Paspalum notatum* Flugge), were selected for study. We needed to know how elevated CO_2 and temperature will affect photosynthesis, respiration, growth, carbohydrate storage dynamics in the rhizomes and stolons, the Carbon and Nitrogen balance processes, and the eventual soil organic matter sequestration of Carbon.

Approach: This study evaluated the growth and C balance dynamics of bahiagrass and rhizoma peanut over a 3-year period at 360 or 700 ppm CO_2 and at temperatures from ambient to +4.5°C imposed above the natural diurnal temperature cycle in temperature-gradient greenhouses (TGGs). Four 27-m long X 4.4-m wide TGGs were constructed in the field over an Arredondo fine sand soil. Rate of ventilation and supplemental heating were regulated to control the temperature gradient in steps of 0.0, 1.5, 3.0, and 4.5°C in successive (5.5 m by 4.4 m) compartments. Ambient (360 ppm) or 700 ppm CO_2 levels were maintained by monitoring and injecting of CO_2. The forages were established April 10, 1995, and temperature gradients and CO_2 treatments have been continuous year-round since May 9, 1995. The forages were irrigated optimally and fertilized with 80 kg N ha^{-1} yr^{-1} in multiple split applications. We evaluated dry matter growth and composition of plant components (leaves, stems, rhizomes, stolons, roots) from small growth samples at 4 to 5 times during the season, and took large-plot herbage yield 3 or 4 times per season using a sickle-bar mower. Leaf and canopy assimilation were measured 3 to 4 times per season. This report summarizes results of the 1995 and 1996 seasons.

Findings: Forage Growth and Establishment: Biomass production of both species increased with elevated CO_2 concentration. Averaged over five sampling dates in 1995, elevated CO_2 increased total biomass accumulation by 52% for rhizoma peanut and 14% for bahiagrass. Elevated CO_2 increased numbers of shoots and rhizomes in rhizoma peanut, and increased leaf number and leaf size in bahiagrass. Increasing temperature accelerated plant establishment and increased early plant dry matter accumulation, leaf area, and leaf appearance rate in 1995. After the establishment year, there was no significant growth response to temperature in 1996. Analyses of growth samples are not complete; however, growth responses to CO_2 in 1996 were visually similar to those observed in 1995.

Findings: Herbage Production: In the establishment year, elevated CO_2 increased harvested herbage of bahiagrass from 321 to 376 g m^{-2} and rhizoma peanut from 318 to 385 m^{-2}, increases of 17% and 21%, respectively. There was no significant temperature effect on herbage production, although there was a trend for increase in bahiagrass herbage with temperature increase. In 1996, we harvested three times. Total seasonal herbage yield, clipped at 4-cm height on plots measuring 1.8 x 4.7-m land area, was 870 and 1010 g m^{-2} for bahiagrass grown at 360 and 700 ppm CO_2, respectively. For rhizoma peanut, total seasonal herbage yield was 1300 and 1650 g m^{-2} at 360 and 700 ppm CO_2, respectively. The response to CO_2 was significant for both species, being 16% for bahiagrass and 27% for rhizoma peanut. The species by CO_2 interaction was significant, meaning that the C_3 rhizoma peanut responded significantly more to CO_2 than did the C_4 bahiagrass. There was no significant temperature effect on herbage production of species.

Findings: Leaf and Canopy Assimilation: Doubling CO_2 increased leaf photosynthesis of rhizoma peanut by 41% in 1995 and 38% in 1996 when averaged over temperature treatments and measurement dates. Doubling

CO_2 increased leaf photosynthesis of bahiagrass by 18% in both 1995 and 1996. Gross canopy photosynthesis of rhizoma peanut was increased 31% in 1995 and 20% in 1996 by doubled CO_2, while canopy photosynthesis of bahiagrass was increased an insignificant 3% in 1995 and 13% in 1996, by doubled CO_2. There was no significant temperature effect on leaf or canopy photosynthesis in either species.

Findings: Tissue Composition and Nutritive Value: In 1995, elevated CO_2 decreases N concentration of leaves of both species by 6 to 9%. Increasing temperature decreased N concentration of final herbage samples of both species. Elevated CO_2 increased total nonstructural carbohydrate (TNC) concentration in leaves of rhizoma peanut by 49%, but had no significant effect on TNC in stem, rhizome, or root. There were no significant effects of CO_2 on TNC of bahiagrass components. Elevated CO_2 and temperature caused small insignificant decreases in forage nutritive quality by decreasing *in-vitro* organic matter digestibility (IVOMD) and increasing neutral detergent fiber.

Findings: Summary: Growth responses to temperature and CO_2 are consistent with expectations for a C_4 tropical grass and a C_3 warm-season legume. Photosynthesis and biomass production of the C_3 rhizoma peanut responded more to CO_2 than did the C_4 bahiagrass. Elevated CO_2 decreased leaf N concentration of both species as anticipated and increased carbohydrate status of rhizoma peanut leaves. There were no negative effects of elevated temperature on growth or photosynthesis of either species

Future Plans: Complete responses of 1996 and 1997 will be reported in a University of Florida Ph.D. dissertation by Yoana Newman. A complete C balance simulation will be completed for the full 3-year period. Effects of N, water, and forage removal will be investigated next as fsactors governing C and N balance and sequestration.

Publications:

Felix B. Fritschi. 1996. Establishment Growth of Perennial Peanut and Bahiagrass in Response to Carbon Dioxide and Temperature. M.S. Thesis, University of Florida.

Boote, K.J., F.B. Fritschi, L.H. Allen, Jr., and L.E. Sollenberger. 1997. Elevated CO_2 and temperature effects on *Paspalum* and *Arachis* forages. Proceedings of the XVIII International Grasslands Congress, Winnipeg, Canada. 9-15.

In addition to NIGEC Symposium presentations, K.J. Boote presented a talk in September 1996 at the Soil and Crop Sci. Soc. of Florida; K.J. Boote presented a poster at the International Grasslands Congress, June 8-19, 1997 in Winnipeg, Canada.

Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Photosynthetic Acclimation of Soybean and Rice to Elevated CO_2, Temperature, and Drought

Principal Scientists: J.C.V. Vu and L.H. Allen, Crop Genetics and Environmental Research, Gainesville, FL

Cooperating Scientists: R.W. Gesch, K.J. Boote, and G. Bowes, University of Florida, Gainesville, FL

ARS GCRP CRIS Number: 6615-11000-004-00D **Date:** 6 October 1997

Problem: Rising carbon dioxide concentration ($[CO_2]$) and other greenhouse-effect gases could change crop productivity through (a) photosynthetic responses (the CO_2 fertilization effect) and (b) other plant growth responses to anticipated global warming and changes in precipitation (soil water availability). Research is required to identify and quantify these responses. Particularly, a basic understanding of the physiological, biochemical and molecular adjustments, or acclimation, of leaf photosynthesis in response to elevated $[CO_2]$ and environmental stresses is essential for precise prediction of crop growth and yield efficiency under future $[CO_2]$ and climate conditions.

Approach: Soybean and rice were grown in outdoor, sunlit, environment-controlled chambers at daytime $[CO_2]$ of 350 (ambient) or 700 (elevated) ppm. Soybean was grown under varying day/night temperatures ranging from 28/18 to 48/38°C. For rice, day/night air temperatures were controlled at 28/21°C, and drought was imposed at panicle initiation growth stage. Leaf photosynthetic rate (P_n) and activity, activation, concentration, kinetic behavior and small subunit transcript (*rbcS*) of ribulose bisphosphate carboxylase-oxygenase (Rubisco) were determined.

Findings: Leaf P_n of both species, when measured at the $[CO_2]$ used for growth, was increased by CO_2 enrichment. High growth temperatures and drought stress decreased P_n, but CO_2 enrichment compensated for the declines. Elevated $[CO_2]$, supraoptimal temperature, and low soil water availability reduced the activity, activation and content of Rubisco. The $K_m(CO_2)$ of the initial Rubisco activity was not affected by elevated $[CO_2]$, as neither supraoptimal temperatures established for soybean, nor severe drought imposed for rice, changed the $K_m(CO_2)$ values. The V_{max} values, however, were reduced under elevated $[CO_2]$ and stress growth conditions. The abundance of *rbcS* transcripts was reduced in soybean plants exposed to elevated $[CO_2]$ and high temperature, and in rice plants subjected to elevated $[CO_2]$ and drought. In the elevated-$[CO_2]$-stressed rice, *rbcS* transcript levels sharply declined within one day, from 75 to 17% of the controls. In rice, the high $[CO_2]$ treatment delayed by one day the low P_n, Rubisco activity and *rbcS* transcript abundance caused by severe drought stress. Thus elevated $[CO_2]$ provided temporary relief for rice from the soil water-deficit situation. When the well-watered (flooded) rice plants were switched from high to ambient $[CO_2]$, they initially showed P_n 10% lower than the ambient-$[CO_2]$ controls, but by 8 days after switching (DAS), leaf P_n and Rubisco activity were up-regulated to the control values. In contrast, flooded rice switched from ambient to high $[CO_2]$ showed an initial increase in P_n above that of the high-$[CO_2]$ control, but by 8 DAS, it had down-regulated to the control value. Rubisco activity decreased as well. Leaf Rubisco content appeared to parallel activity for both mature and expanding leaves throughout the experiment.

Future Plans: Analyze changes in carbohydrate pool sizes and Rubisco transcripts to determine to what extent they parallel the changes in leaf P_n and Rubisco activity/content that resulted from switching the $[CO_2]$. Evaluate the effects of nitrogen supply on photosynthetic acclimation of rice grown under elevated $[CO_2]$.

Publications: (June 1996-September 1997).

Vu, J.C.V., L.H. Allen, Jr., K.J. Boote, and G. Bowes. 1997. Effects of elevated CO_2 and temperature on photosynthesis and Rubisco in rice and soybean. Plant Cell Environ. 20:68-76.

Vu, J.C.V., A.H. Pennanen, J.T. Baker, L.H. Allen, Jr., G. Bowes, and K.J. Boote. 1997. Elevated CO_2 and water deficit effects on photosynthesis, ribulose bisphosphate carboxylase-oxygenase, carbohydrates and chloroplast ultrastructure in rice. Physiol. Plant. (Submitted).

Title: Heat and Anaerobic Soil Treatments as Alternatives to Methyl Bromide in Vegetable Production

Principal Scientists: L.H. Allen, Jr., T.R. Sinclair, J.C.V. Vu, C. Chase, and D. Sotomayor, Crop Genetics and Environmental Research, Gainesville, Florida

Cooperating Scientists: Z. Chen, D.O. Chellimi, S.J. Locasio, and D.W. Dickson University of Florida

ARS GCRP CRIS Number: 6615-12000-001-00D **Date:** 22 September 1997

Problem: Preplant soil fumigation with methyl bromide has been used as a universal soil disinfestation agent for production of vegetable and fruit crops, mainly in Florida and California. Methyl bromide for these purposes will no longer be available after January 1, 2001. Many researchers are investigating alternative chemicals, but few are investigating alternative management practices. Nematodes (esp. root-knot nematode) and weeds (esp. purple nutsedge) are main problems, along with fungal and bacterial phytopathogens.

Approach: Two alternative management practices are being investigated: (1) Heat stress imposed by soil solarization (i.e., soil heating under plastic) and (2) Anaerobic stress imposed by periodic soil flooding. Heat stress. Improved clear plastic films with enhanced thermal radiation trapping properties were acquired and tested in comparison with other plastics and soil treatments. These films were designed to transmit the maximum amount of solar radiation directly to the soil surface for heating, while decreasing the emission of thermal radiation away form the field. Soil temperature profiles were measured under the plastic treatments, as well as visual observations and yield measurements. Anaerobic stress. Soil flooding is a possible option only for seasonally high water table soils that must be carefully managed (provided with drainage and irrigation) for crop production. Experiments were conducted on shallow flooding (5-cm depth) for 6 to 12 weeks as possible controls for rootknot nematode and purple nutsedge. Soil redox was measured continuously in one block of treatments. Direct measurements of nematode populations in the soil and bioassays of the rate of infestation on test plants were conducted. Purple nutsedge plants were counted to measure impacts of anaerobic soil treatments.

Findings: Heat stress. The improved plastics rendered an increase of soil temperatures during the preplant solarization treatments which provided an effective control of purple nutsedge infestation during the following cropping period. Solarization also decreased root-knot nematode infestation, but not to the degree of methyl bromide injections. The improved radiation admission and retention properties of the plastic offers a definite alternative to methyl bromide. Use of solarization in conjunction with other treatments and management practices should be a viable alternative even in Florida's sunshine and rainfall conditions. Anaerobic stress. Shallow flooding treatments drastically decreased the viable population of rootknot nematodes and furthermore decreased the development of galls on bioassay tomato plants grown in the treatment soils even more noticeably. However, shallow flooding did not control purple nutsedge. Followup studies with flooding up to 30-cm is more promising, but this treatment may not be practical.

Future Plans: Both heat stress and anaerobic soil stress studies will continue in 1998.

Publications: (June 1996 - September 1997).

Sotomayor, D., and L.H. Allen, Jr. 1996. Control of nematodes and weed populations by pre-plant soil flooding? Paper No. 97. In 1996 Annual International Research Conference on Methyl Bromide alternatives and Emissions Reductions, 4-6 November 1996, Orlando, Florida.

Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Soybean Response to CO_2 and Drought: Leaf Gas Exchange and Symbiotic N_2 Fixation

Principal Scientists: T.R. Sinclair and L.H. Allen, Jr.

Cooperating Scientists: R. Serraj

ARS GCRP CRIS Number: 6615-11000-004-00D & -12210-001-00D **Date:** 22 Sept. 1997

Problem: Rising carbon dioxide and other greenhouse-effect gases might change crop productivity through (a) increased photosynthetic response to elevated CO_2, (b) water conservation resulting from diminished stomatal conductance and transpiration, and (c) other plant growth responses to anticipated global warming (higher temperatures) and changes in precipitation (soil water availability). Nutrient requirements may also change. Actual crop response may vary due to an interaction of these factors. Drought can be the greatest limit to crop production. Although it is well-known that legume crops such soybean respond well to elevated CO_2, no significant research has been conducted on the interaction of elevated CO_2 and drought on N_2 fixation.

Approach: Experiments were conducted to determine the response of soybean (cv. Braxton) leaf growth, transpiration, root nodulation, and N_2 fixation to elevated CO_2 and soil drying. Experiments were conducted in November 1995 and April 1996 in two greenhouses maintained at 360 (ambient) and 700 ppm CO_2. Plants were grown for 4 weeks in pots in a greenhouse at ambient CO_2 and then transferred to the treatment greenhouses. Water was allowed to be used from the pots in each treatment in a controlled fashion so that all plant-available soil water was used in 17 days. Acetylene reduction activity was measured as a surrogate for N_2 reduction each afternoon during the two experiments.

Findings: For these short experiments, stimulation of biomass accumulation (shoot, root, and nodules) by CO_2 was significant only under drought stress. Elevated CO_2 decreased water loss rates and increased leaf area and photosynthetic rate under both well watered and drought stress conditions.

Under drought stress conditions, elevated CO_2 provided a substantial delay in the decrease of N_2 fixation rates associated with soil drying, and also allowed plants under drought to increase the number and mass of nodules. For both CO_2 treatments, drought stress induce a substantial accumulation of total nonstructural carbohydrate (TNC) in the nodules as N_2 fixation declined, which suggests that nodule activity under drought might not be carbon limited. Under drought, ureide concentration increased in all plant tissues, especially nodules but exposure to elevated CO_2 resulted in a substantially lower ureide accumulation in leaves. Since high ureide concentration may inhibit N_2 fixation, elevated CO_2 through greater photoassimilate production, might decrease this inhibition.

Carbon dioxide benefits N_2 fixation under drought by the following ways:

1. Decreased rates of soil water use so that N_2 fixation can be prolonged (as well as photosynthesis).
2. Slows the decline of N_2 fixation as soil water runs out; maintains nodule growth.
3. Decreases the tendency for ureide accumulation inhibition of N_2 fixation

Future Plans: Determine the role of CO_2 in maintaining N_2 fixation over a series of droughts. Determine the role of CO_2 on N_2 fixation of Rhizomous perennial peanut during drought.

Publications: (June 1996-September 1997).

Serraj, R., L.H. Allen, Jr., and T.R. Sinclair. 1998. Soybean growth and gas exchange in drought under carbon dioxide enrichment. (prepared for Global Change Biology).

Serraj, R., L.H. Allen, Jr., and T.R. Sinclair. 1998. Soybean nodulation and N_2 fixation response to drought under carbon dioxide enrichment. (prepared for Global Change Biology).

BIOGEOCHEMICAL CYCLES

Biogeochemistry Subgroup Summary Report

The biogeochemical subgroup research update and discussion session was attended by 11 scientists working in the area. Those in attendance were: Marvin Shaffer, Ardell Halvorson, Gordon Hutchinson, Ken Potter, Al Frank, Bill Emmerich, Hyrum Johnson, Hartwell Allen, Hugo Rogers, Arvin Mosier, and Jerry Schuman.

The research discussed within this group was identified as either N-gas emissions, methane emissions, and carbon dioxide/carbon dynamics. We summarized the research findings reported as such.

I. N-Gas Emissions:

a. Very little research being done to evaluate management strategies to reduce N emissions.

1. Nitrification inhibitors have been utilized but limited new work going on in this area.
2. Generally believed that increasing N-use efficiency is the best way to reduce N emissions.
3. NH^+_3 is a major issue as it relates to animal waste management. Work done in the 1970's addressed this issue and showed feedlot management and waste management strategies could greatly limit its volatilization; however, this information doesn't seem to readily accepted and implemented.

b. Reduced tillage has not shown consistent effects on N emissions. Generally N emissions is more dependent upon soil moisture.

c. Prescription farming should increase N-use efficiency and hence reduce N emissions.

II. Methane Emissions:

a. All aerobic soils take up methane. Tillage reduces the soils' ability to act as a sink for methane; however, the mechanisms are not understood.

b. We have a good understanding of methane emissions from swine wastes.

c. Research has shown that water table draw down basically eliminates methane emission in rice production without affecting yield.

d. The largest single source of methane is from ruminant animals. Increased forage/feed quality reduces methane emission from ruminants.

III. Carbon Dioxide/Carbon Dynamics:

a. Reducing clean tillage and wheat-fallow enhance CO_2 assimilation/sequestration.

b. Maintaining appropriate management of grasslands enhances CO_2 sequestration and enhances soil organic carbon content.

c. Use of cover crops enhances CO_2 sequestration. Crops with higher shoot:root ratios are best CO_2 assimilators.

Recommendations:

1. We need to point out to our customers the importance of tillage practices and grazing management on global change.

2. We need to explain and evaluate how global change will affect management strategies and alternatives in cultivated agriculture and grasslands.

3. Models, such as NLEAP, can be used to evaluate N emissions; however, we need further validation of these models in this setting.

4. The biogeochemical subgroup members believe that meeting every other year would be adequate for knowledge transfer and research planning in the Global Change program.

Carbon and Nitrogen Cycling in Mixed- and Short-Grass Prairie

Principal Scientists: GE Schuman, J.D. Reeder, J.A. Morgan, Rangeland Resources Research. Cheyenne, WY and Fort Collins, CO

Cooperating Scientists: R.H. Hart, D.R. LeCain, E.M. Taylor

ARS GCRP: Research Area I, Program Element B, Objective 1, Task 2

CRIS: 5409-11000-001-00D

Problem: The effects of management strategies on carbon and nitrogen cycling in native rangeland ecosystems are not clearly understood. If management alternatives affect carbon and nitrogen cycling then long-term sustainability of the system might be at risk.

Approach: Field studies are underway to assess the effects of long-term grazing management alternatives on the C and N balance of both a mixed-grass and short-grass prairie ecosystem. The mixed-grass prairie has been grazed at light and heavy stocking rates under a continuous season-long system for 15 years and the short-grass prairie ecosystem has been grazed for 57 years using stocking rates about 50% of that of the mixed-grass prairie and a similar management system. Stocking rates of the mixed- and short-grass pastures result in about the percentage forage utilization. Treatments evaluated include the light and heavy stocking rate and non-grazed exclosures. Field sampling for C and N includes soil, roots, litter, standing dead plant material, and annual production.

Findings: Twelve years of grazing the mixed-grass prairie under the light and heavy stocking rate did not change the total masses of C and N in the plant-soil (0-60 cm) system, but did change the distribution of C and N among the system components. The primary change was expressed as a significant increase in the masses of C and N in the root zone (0-30 cm) of the soil profile of the grazed pastures. Total soil organic C and N masses in the surface 30 cm of the soil profile of the exclosure was significantly lower than that observed in both of the grazed pastures. Eliminating grazing entirely (exclosure) resulted in a build-up of dead plant material (72% of the aboveground vegetative component) on the soil surface. Rapid cycling of C and N through animal excreta, and the enhanced physical breakdown and soil incorporation of surface litter by hoof action are absent in the non-grazed exclosure and partially account for the differences observed. Moreover, the buildup of the standing dead and surface litter in the exclosure result in a cooler and more moist environment that slows decomposition processes and increases the potential for denitrification losses of N. We believe the lower levels of soil (0-30 cm) C and N in the exclosure are due to a combination of slower decomposition and recycling of C and N in the soil, increased losses of C and N from the plant-soil system, and redistribution of C and N within the plant-soil system. The companion evaluations involving the short-grass prairie site have shown some similar trends; however, these pastures have shown more variation in subsoil horizons even though the soil series is the same in all treatments. No significant differences were found among the heavy, light and non-grazed treatments in total C and N in the soil A horizon (0-15 cm). But total masses of organic C and N in the 0-60 cm solum were significantly higher in the heavily grazed pasture

than in the lightly grazed or non-grazed exclosures. The higher levels of C and N in the soil profile of the heavily grazed treatment are due in part to a significantly higher root biomass (0-60 cm) and may also be influenced by a higher B horizon clay content. Data analysis on the vegetation components and total system C and N balances of the system are not completed.

Future Plans: These studies will be completed this next year and data summarizations and publications prepared. We are considering sampling a mixed-grass prairie system that has been managed by the Forest Service for several decades and grazed at lower stocking rates than observed to-date. This research has led to studies assessing the effects of grazing on photosynthesis and hence CO_2 sequestration and also a study to assess the rate of soil organic C formation using isotopic CO_2.

Publications:

Schuman, GE, J.D. Reeder, J.T. Manley, R.H. Hart, and W.A. Manley. 1998. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecological Applications (In review).

Schuman, GE, J.D. Reeder, R.H. Hart, and J.A. Morgan. 1997. Impact of livestock grazing on the carbon and nitrogen balance of a mixed-grass prairie. Agron. Abstracts. (In press)

Rceder, J.D., GE Schuman, J.A. Morgan, D.R. LeCain and R.H. Hart. 1997. Shortgrass steppe soil carbon and nitrogen responses to grazing. Agron. Abstracts. (In press)

Using Isotopes to Evaluate Carbon and Nitrogen Dynamics in a Mixed-Grass Rangeland

Principal Scientists: G.E. Schuman, G.L. Hutchinson, J.D. Reeder, H. Skinner, J.A. Morgan., Rangeland Resources Research, Cheyenne, WY and Fort Collins, CO; Soil-Plant-Nutrient Research, Fort Collins, CO; Great Plains Systems Research, Fort Collins, CO

Cooperating Scientists: R.H. Hart, D.R. LeCain, E.M. Taylor

ARS GCRP: Research Area I, Program Element B, Objective 1, Task 2

CRIS: 5409-11000-001-00D

Problem: Livestock management has been shown to affect C and N dynamics of native rangeland ecosystems. However,questions of magnitude and time-frame are important in assessing how CO_2 and N sequestered by the plant community of variously managed ecosystems affects system dynamics.

Approach: Field studies employing stable isotopes were initiated in 1997 to investigate (1) soil organic matter dynamics as a function of grazing intensity, C3 vs C4 species composition, and water availability, and (2) the effect of various factors of C and N partitioning withing th soil-plant community. Sixty-six microplots in each of three grazing treatment, continuous light, continuous heavy and non-grazed exclosure, were established by pushing PVC cylinders (25 cm diameter by 33 cm height) about 31 cm into the thawed soil. $^{13}CO_2$ and $K^{15}NO_3$ were applied during active early spring grass growth. At various phenological stages of the primary species, 6 cylinders were removed from each grazing treatment. Five sets of cylinders will be removed in 1997, 4 sets in 1998, and 2 sets in 1999. Above-ground biomass is separated int live C3 plants, live C4 plants, standing dead plants, crowns, and litter. The soil is sectioned into 0-5 cm, 5-15 cm, and 15-30 cm layers, and all roots removed from each layer. To determine the effects of soil spatial variability and water availability on results from the labeled cylinders, small rectangular field plots not treated with C and N isotopes have also been established adjacent to the cylinders in the heavy grazing and non-grazed treatments. Additional water is applied weekly to half of the rectangular plots, which are cored the week after the cylinders are removed and separated into similar soil and plant components. All plant samples are analyzed for carbohydrate content and for total and isotopic C and N. Measurements of the soil fractions include water content, bulk density, total and isotopic C and N, total and isotopic NH_4^+ and NO_3^-, microbial biomass, and aerobically mineralizable C and N.

Findings: This study was initiated in 1997. Four sets of cylinders and cores have been collected and processed. Laboratory analyses are in progress. No conclusions can be drawn at this time.

Future Plans: This study will be continued through the 1999 growing season.

Publications: None

Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Soybean Response to CO_2 and Drought: Leaf Gas Exchange and Symbiotic N_2 Fixation

Principal Scientists: T.R. Sinclair and L.H. Allen, Jr.

Cooperating Scientists: R. Serraj

ARS GCRP CRIS Number: 6615-11000-004-00D & -12210-001-00D   **Date:** 22 Sept. 1997

Problem: Rising carbon dioxide and other greenhouse-effect gases might change crop productivity through (a) increased photosynthetic response to elevated CO_2, (b) water conservation resulting from diminished stomatal conductance and transpiration, and (c) other plant growth responses to anticipated global warming (higher temperatures) and changes in precipitation (soil water availability). Nutrient requirements may also change. Actual crop response may vary due to an interaction of these factors. Drought can be the greatest limit to crop production. Although it is well-known that legume crops such soybean respond well to elevated CO_2, no significant research has been conducted on the interaction of elevated CO_2 and drought on N_2 fixation.

Approach: Experiments were conducted to determine the response of soybean (cv. Braxton) leaf growth, transpiration, root nodulation, and N_2 fixation to elevated CO_2 and soil drying. Experiments were conducted in November 1995 and April 1996 in two greenhouses maintained at 360 (ambient) and 700 ppm CO_2. Plants were grown for 4 weeks in pots in a greenhouse at ambient CO_2 and then transferred to the treatment greenhouses. Water was allowed to be used from the pots in each treatment in a controlled fashion so that all plant-available soil water was used in 17 days. Acetylene reduction activity was measured as a surrogate for N_2 reduction each afternoon during the two experiments.

Findings: For these short experiments, stimulation of biomass accumulation (shoot, root, and nodules) by CO_2 was significant only under drought stress. Elevated CO_2 decreased water loss rates and increased leaf area and photosynthetic rate under both well watered and drought stress conditions.

Under drought stress conditions, elevated CO_2 provided a substantial delay in the decrease of N_2 fixation rates associated with soil drying, and also allowed plants under drought to increase the number and mass of nodules. For both CO_2 treatments, drought stress induce a substantial accumulation of total nonstructural carbohydrate (TNC) in the nodules as N_2 fixation declined, which suggests that nodule activity under drought might not be carbon limited. Under drought, ureide concentration increased in all plant tissues, especially nodules but exposure to elevated CO_2 resulted in a substantially lower ureide accumulation in leaves. Since high ureide concentration may inhibit N_2 fixation, elevated CO_2 through greater photoassimilate production, might decrease this inhibition.

Carbon dioxide benefits N_2 fixation under drought by the following ways:

1. Decreased rates of soil water use so that N_2 fixation can be prolonged (as well as photosynthesis).
2. Slows the decline of N_2 fixation as soil water runs out; maintains nodule growth.
3. Decreases the tendency for ureide accumulation inhibition of N_2 fixation

Future Plans: Determine the role of CO_2 in maintaining N_2 fixation over a series of droughts. Determine the role of CO_2 on N_2 fixation of Rhizomous perennial peanut during drought.

Publications: (June 1996-September 1997).

Serraj, R., L.H. Allen, Jr., and T.R. Sinclair. 1998. Soybean growth and gas exchange in drought under carbon dioxide enrichment. (prepared for Global Change Biology).

Serraj, R., L.H. Allen, Jr., and T.R. Sinclair. 1998. Soybean nodulation and N_2 fixation response to drought under carbon dioxide enrichment. (prepared for Global Change Biology).

Title: **Carbon sequestration in seeded pastures, native pastures, and conservation tillage systems.**

Principle Scientists: A. B. Frank, B. J. Wienhold, A. D. Halvorson, and J. F. Karn

ARS GCRP: Res. Areas I; Prog. Elements: B; Objs: 1; Tasks: 2

CRIS No. 5445-21000-005-00D; 5445-12130-003-00D

Problem: The influence of management on soil carbon and N changes in the Northern Great Plains is not defined for native grasslands, seeded pastures, and conservation tillage systems.

Approach: Determine CO_2 fluxes from grazed and nongrazed native and seeded pastures. Compare soil carbon in pastures seeded in 1986 and managed as CRP or grazed. Sample cropping systems-conservation tillage plots to determine effects of cropping sequence, tillage, and N applications over a 13-year period on soil carbon, nitrogen, and soil property changes.

Findings: Bowen ratio-energy balance techniques gave net carbon dioxide fluxes during daylight hours of 1027, 683, and 694 g CO_2/m_2 from Apr 22 to Nov 3, 1996 for native nongrazed (NNG), native grazed (NG), and western wheatgrass grazed (WWG) pastures, respectively. Net daily (24 hr) fluxes were greatly reduced due to nighttime soil and plant respiration. Soil CO_2 efflux was measured every 2-3 wks and averaged 0.11, 0.14, and 0.16 mg $CO_2/m_2/s$ for the NNG, NG, and WWG pastures, respectively. Live vegetation production peaked in mid-July averaging 1692, 1844, and 2046 kg/ha for the NNG, NG, and WWG pastures, respectively. Results show that the grazed pastures sequestered less carbon than the nongrazed native pastures.

Several physical, chemical, and biological properties commonly used to evaluate soil quality were compared in the 65-acre cropping system study. A number of commonly measured soil quality parameters increased as cropping intensity increased and tillage intensity decreased.

Bulk density was greater in the fallow phase of the crop-fallow system; was greater in the annual cropping system than in the crop-fallow system; and increased as tillage intensity decreased in both cropping systems.

Total N and C were similar between the two phases of the crop-fallow system; were greater in the annual cropping than in the crop-fallow system; and increased as tillage intensity decreased in the annual cropping system. N-mineralization rates were higher in the fallow phase of the crop-fallow system; were higher in the annual cropping system than in the crop-fallow system; and increased as tillage intensity decreased in both system. Inorganic N was similar between phases in the crop-fallow system; was similar between the crop-fallow system and the annual cropping system; and increased as tillage intensity decreased in the annual cropping system.

Fungi numbers were greater in soil from the fallow phase of the crop-fallow system; were greater in soil from the annual cropping system than in the crop-fallow system; and increased as tillage intensity decreased in the annual cropping system. Bacteria and actinomycete numbers were similar across treatments.

Future Plans: Carbon dioxide flux measurements will be continued to obtain yearly variation effects and to evaluate for accumulative effects of nongrazing on total carbon sequestration. The CRP/grazed pasture study sampled in 1988, 1992, and 1996 will be completed.**We will continue to evaluate tillage practices by enumerating fungi, bacteria, and actinomycetes; quantifying microbial biomass, microbial biomass C, and microbial biomass N; measuring the amount of potentially mineralizable N; and conducting a litter decomposition study.

Publications: Frank, A.B., and A. Bauer. 1996. Temperature, nitrogen, and carbon dioxide effects on spring wheat development and spikelet numbers. Crop Sci. 36:659-665.

Organic Carbon Content of Central Mexico Soils

Principle Scientists: Kenneth N. Potter
H. Allen Torbert
Jaimie Velazquez

ARS GCRP: **Res. Area I:** Structure and Function;
Prog. Element B: Biogeochemical Systems;
Obj. 2: Evaluate carbon and nutrient cycles as they are influenced by anthropogenic activities;
Task 3: Evaluate and study the impact of tillage and residue management systems on C and N cycles

CRIS Numbers: 6206-11120-001

Problem: Tillage and residue management effects on soil carbon sequestration vary depending upon the local climate, especially temperature and rainfall amounts. Climatic effects are difficult to quantify because of the lack of uniform management practices in a range of climatic conditions.

Approach: Researchers in central Mexico are currently in the second year of conducting a uniform tillage and residue management experiment at numerous locations with a wide range of soil, annual rainfall, and mean annual temperature conditions. Seven locations within this broader experiment have been selected for additional study of management effects on soil organic carbon. Management treatments include moldboard plow after removal of residue; Disk tillage after removal of residue; no-till management with residue retained on the soil surface; no-till management with 2/3 of residue retained; no-till management with 1/3 of residue retained; and no-till management with no residue retained (bare). Soil cores have been obtained and sectioned into 0-2, 2-4, 4-7, 7-10, 10-20, and 20-30 cm depth increments. Soil organic carbon, bulk density, and soil texture has been determined for each site/treatment combination.

Findings: With only two years of continuous management, treatment effects are not yet well defined. The current data are best considered as baseline data set for determination of future treatment effects. Still, there appears to be some stratification of organic carbon, with higher concentrations occurring in the surface 2-4 cm of no-till with larger amounts of residue retained on the soil surface. Total soil organic carbon content has not been significantly affected by the imposed management treatments.

Future Plans: The management treatments shall be continued for four to five years, after which time the plots shall be resampled and management effects evaluated. During this time, the current experiment manager shall pursue a graduate degree while researching the potential carbon and nitrogen mineralization of the selected soils.

Publications:

Potter, K.N., O.R. Jones, H.A. Torbert, and P.W. Unger. Crop rotation and tillage effects on organic carbon sequestration in the semiarid Southern Great Plains. Soil Science: 162:140-147. 1997.

Torbert, H.A., K.N. Potter, and J.E. Morrison, Jr. Tillage intensity and fertility effects on nitrogen and carbon cycling in a vertisol. Commun. in Soil Sci. Plant Anal. 28:699-710. 1997.

Torbert, H.A., K.N. Potter, and J.E. Morrison, Jr. Tillage intensity and crop residue effects on nitrogen and carbon cycling in a vertisol. Commun. in Soil Sci. Plant Anal. (In press).

Potter, K.N., H.A. Torbert, O.R. Jones, J.E. Matocha, J.E. Morrison, Jr., and P.W.Unger. Distribution and amount of soil organic carbon in long-term management systems in Texas. Soil Till. Res. (In submission).

Title: Carbon Dioxide and Climate Change Effects on Crops and Trace Gas Exchange with the Atmosphere

Subproject: Response of Sugarcane to Carbon Dioxide and Temperature

Principal Scientists: L.H. Allen, Jr. and J.C.V. Vu, Crop Genetics and Environmental Research Unit, Gainesville, Florida

Cooperating Scientists: T.R. Sinclair and J.D. Ray, ARS (and Sara Clendenin, ARS summer student Research Apprentice)

ARS GCRP CRIS Number: 6615-11000-004-00D Date: 22 September 1997

Problem: Rising carbon dioxide and other greenhouse-effect gases will change crop productivity through (a) photosynthetic response (the CO_2 fertilization effect) and (b) other plant growth responses to anticipated global warming (temperature effects) and changes in precipitation soil water availability). Research is required to quantify these productivity changes, and to identify management and genetic adaptations to ameliorate potential negative impacts.

Approach: On this subproject, studies are being conducted in 27.4-m X 4.3-m temperature-gradient greenhouses. These greenhouses provide four 5.5-m experimental zones along the length with differences maintained at 1.5° C steps above ambient by a combination of heaters, solar radiation, and computer-controlled ventilation fans. Temperature x CO_2 treatments are provided by paired CO_2-enriched and ambient-CO_2 greenhouses. Each temperature zone contained 8 vats containing 4 sugarcane cultivars, for a total of 32 vats per greenhouse. Half of the vats were filled with mineral soil and half with organic soil, and half of these have water tables that were set to 23 cm. The treatments are CO_2 (360 and 700 PPM), temperature (baseline, +1.5, +3.0, and +4.5° C), soil type (mineral vs. organic), water table (23 cm vs. 60- cm drained profile), imposed on four cultivars (CP72-2086, CP73-1547, CP88-1508, and CP80-2086).

Sugarcane seed pieces were planted on January 13, 1997 in a greenhouse seedbed, and vegetatively germinated plants were transplanted into the experimental greenhouses on March 21, 1997. Leaf photosynthetic rate measurements were made just prior to the first harvest in late June. Selected harvests were conducted in late June and early July 1997. Leaf samples were taken and preserved in liquid nitrogen for later determination of rubisco, PEP carboxylase, and SPS. Measurements on main stems were: number of green leaves per plant, leaf area, leaf fresh weight, leaf dry weight, mainstem length, mainstem fresh weight, mainstem dry weight, juice volume, hydrometer readings of juice soluble solids, and Brix determinations. Next, above-ground components of all plants were harvested and total fresh weight measured. Total fresh weight of mainstems harvested previously were added to these totals. Then, the number of tillers (large, dead, and total) were counted.

Doubled carbon dioxide concentration increased the following components of plant growth: Leaf number = 7%; Leaf area = 15%; Leaf fresh weight = 13%; Leaf dry weight = 8%; Mainstem length = 32%; Mainstem fresh weight = 31%; Mainstem dry weight = 23%; Juice volume = 40%; Total fresh weight = 25%; SubTotal dry weight = 19%; Juice dry weight = 36%; Total dry weight = 21%.

Total fresh weight increase due to elevated carbon dioxide determined from the whole-crop harvest was somewhat less at 16%.

Increasing temperatures caused a slight downward trend in sugarcane yield regardless of CO_2 treatment.

Fresh weight of sugarcane grown in mineral soil was about 27% greater than in organic soil; however, this effect was due to higher nitrogen fertilization of the mineral soil. In the peat soil of this study, mineralization of organic soil did not provide sufficient nitrogen.

Water table treatments were not implemented soon enough to have any effect. The ratoon crop has been re-established, and water table effects will be determined on the second crop.

Cultivar yields were: CP 73-1547 > CP 80-1827 > CP 88-1508 > CP 72-2086.

The number of tillers per plant was higher in the doubled CO_2 treatment.

<u>Potential impact of findings on science and users:</u> The results show that rising CO_2 may benefit sugarcane production more than the anticipated 10% increase for a doubling of carbon dioxide for a C_4 species. The scientific challenge will then be to determine the physiological reason for this yield promotion by elevated CO_2. The apparent increase in dry weight, fresh weight, and juice should lead to greater yields and perhaps an earlier harvest period as CO_2 continues to rise.

Future Plans: We plan to continue this subproject for at least 2 years, and obtain ratoon sugarcane harvests late in 1997 and twice in 1998. We plan to make detailed investigations of the root systems of the four cultivars to determine if there are any differences in survival and growth in flooded conditions. We have built an apparatus to measure the rate of transport of oxygen from shoot to roots, and plan to determine if there are any cultivar differences.

Publications: (June 1996- September 1997). None for this subproject.

Simulation of Regional Soil Nitrogen Gas Fluxes Using NLEAP

Principal Scientists: M.J. Shaffer and C. Xu
Cooperating scientists: M.K. Brodahl, G. Hutchinson, and R.F. Follett

ARS GCRP: Res. Areas: I ; Prog Elements: AB; Objs: 3, 3; Tasks: 3,4

CRIS Number : 5402-61660-004-00D

Problem: The need exists for an effective and efficient means of simulating emissions of nitrogen gases from soils across broad geographical areas as a function of soil properties, climate and management inputs.

Approach: This is a simulation modeling project with some field and laboratory work required to fill critical knowledge gaps and provide specific model validation data to calibrate and test the NLEAP model for soil gaseous N losses under selected agricultural conditions. The NLEAP model is being modified to include nitrogen greenhouse gas components.

Findings: Effective evaluation of alternative management strategies to control global warming requires tools for simulating emissions of nitrous oxide (N_2O) from soils across a range of soil property, weather, and management inputs. Models can be used to simulate soil N_2O emissions as a function of soil moisture, temperature, nitrogen content and other factors. We modified the nitrification and denitrification submodels of the Nitrate Leaching and Economic Analysis Package (NLEAP) model to simulate daily N_2O emissions. Field parameterization and validation experiments for N_2O gas emissions were conducted on an Ulm clay loam soil (a fine montmorillonitic, mesic Ustollic Haplargid) and an on-farm swine effluent study on a Valent sandy soil (Mixed, mesic Ustic Torripsamments), respectively. The unitless model parameters α_N, α_w, and α_d were calibrated as 0.065, 0.050 and 0.520 separately and then used in the validation study. The trends and magnitudes of simulated N_2O emissions were statistically consistent with the results obtained from the field experiments (r=0.78). Experimental results showed that the decline of N_2O emission rates from 70 to 2 g N ha^{-1} day^{-1} during the growing season was related to soil nitrogen content decline from 33 to 4 mg kg^{-1}. Simulated effects of field management on annual N_2O emissions indicated that variations in tillage systems, nitrogen application rates, and irrigation rates had significant influence on predicted N_2O emissions.

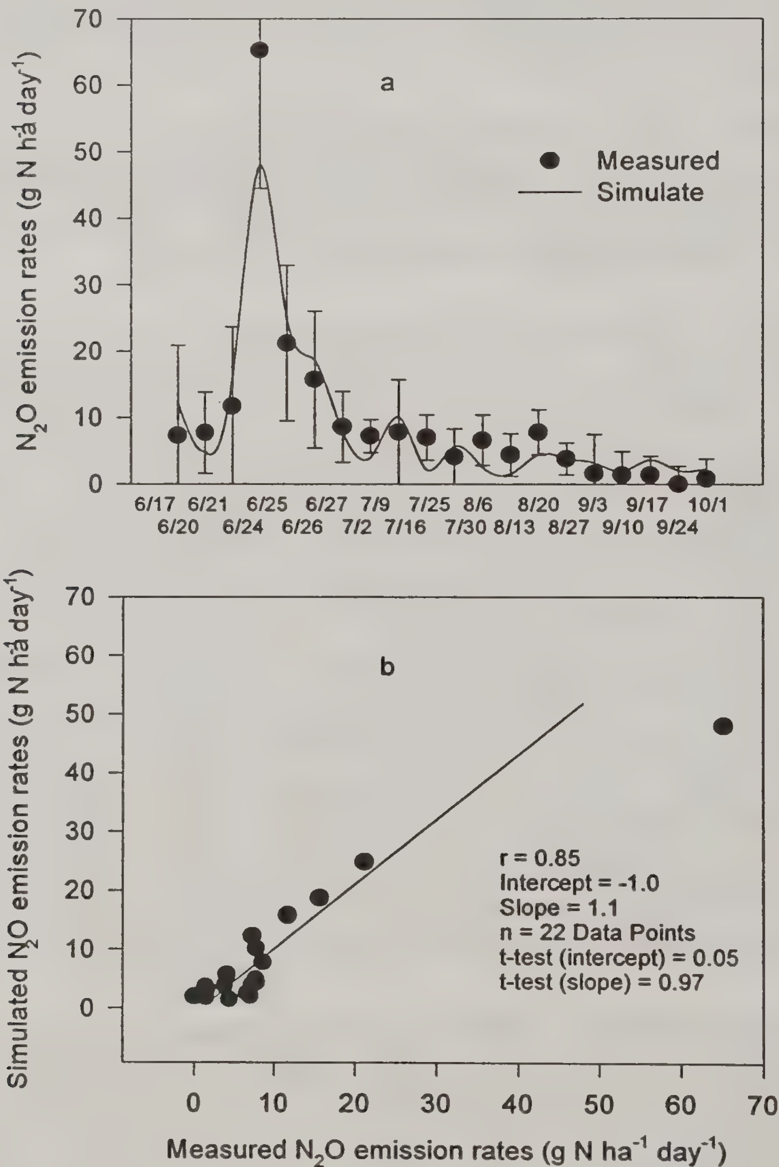
Future Plans: Collect field and laboratory data on soil gaseous N losses under selected cropping, management and soil conditions to test and validate the modified NLEAP-N2O model, and use this information to continue development of NLEAP-N2O as an effective tool to develop the national data base of nitrous oxide emissions and nitrate leaching by the NRCS. Demonstrate the utility of using the NLEAP-N2O model in conjunction with a Geographical Information System to estimate soil emissions of N_2 and N_2O gases across broad landscape and regions.

Publications:

Xu, C., M.J. Shaffer, and M. Al-kaisi. 1997. Simulating the impact of management practies on nitrous oxide emissions. Soil Sci. Soc. Am. J. (in press).

Xu, C. and M.J. Shaffer. 1996. NLEAP simulation of nitrogen gas emissions. P. 33. *In* Agronomy abstracts. ASA, Madison, WI.

Xu, C. and M.J. Shaffer. 1997. Nitrous oxide emissions across landscapes and regions. P. 39. *In* Agronomy abstracts. ASA, Madison, WI.



SOIL-C STORAGE WITHIN SOIL-PROFILES OF THE HISTORICAL GRASS LANDS OF THE USA.

R.F. Follett and E.G. Pruessner - Coinvestigators: J. Kimble[1] and Susan Samson-Liebig[1].

PROBLEM: Vast reserves and the potential to sequester immense amounts of carbon (C) in soils exists in the historical grasslands of the USA (HG). These soils are important as a source-sink in global C cycling. Large areas within the HG are converted from cropland to the Conservation Reserve Program (CRP). Research indicates that CRP enhances C sequestration, but the magnitude is uncertain as is the importance of C gains or losses at deeper soil-profile depths. Another consideration is that CRP contracts are beginning to expire; millions of hectares of CRP land may return to production. Thus, much of the C that the CRP program helped sequester is at risk to being recycled back to the atmosphere as CO_2.

APPROACH: A collaborative effort is underway with the National Soil Survey Laboratory (NSSL) of the NRCS in Lincoln, NE to collect detailed soil-profile measurements. Use of these data, with STATSGO or other data bases, will allow estimates of soil-C storage in HG soils and the influence of management (cropped vs. CRP vs. native grassland). Soils are sampled by horizon from pits (~ 2m deep) at sites along precipitation and temperature gradients. At every site, a separate pit is sampled for each of the three managements; all pits are in the same map unit and on a similar geomorphic setting, even though soil series may change because of management. Soil-physical, -mineralogical, -micromorphological, and -chemical characterizations are by the NSSL. The Fort Collins laboratory is responsible for measurements of various C pools (i.e. total-organic, identifiable plant material, particulate organic matter, mineral associated, and microbial biomass-C). Isotopic analyses for $^{13}C/^{12}C$ ratios and ^{14}C dating will be done on selected samples to better assess issues related to C-sequestration processes and timing.

RESULTS: Sites have been sampled in CO, NE, IA, TX, MT, MO, and MN and the samples are at various stages of analyses. The results thus far indicate that CRP has resulted in large increases in aggregate stability compared to cropland. For sites in CO, NE, and IA, average aggregate stability for surface soils are 23, 20, and 4 (%<5 mm) in CRP, native, and cropland soils, respectively. There are also increases in organic C in the top 10 cm in CRP versus cropland, though they have not reached the levels of the native soil. Additionally, average soil microbial biomass-C (kg/ha) in the 0-60 cm depth is 28% higher in CRP and 81% higher in native than in cropland soils.

FUTURE PLANS: Field collection of samples will resume this coming spring. The focus at that time will be completing our field sampling at sites in OK and ND.

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[1]NRCS, Lincoln, NE

PERFORMANCE OF CHAMBERS FOR MEASURING TRACE GAS EXCHANGE

Principal Scientists:	G.L. Hutchinson, G.P. Livingston (Univ. Of Vermont), W. Yang
Cooperating Scientists:	R.W. Healy and R.G. Striegl (USGS Water Resources Division), H.K. Iyer (Colo. State Univ.)
ARS/GCRP:	Research Area I, Program Element B, Objective 3, Tasks 1, 4, 6, 8
CRIS Number:	5402-11000-004-00D

PROBLEM: Chambers play a critical role in research concerning surface-atmosphere trace gas exchange, so understanding their performance, accuracy, and limitations is essential to properly interpret published trace gas budgets, to develop and validate trace gas exchange models, and to conduct experimental studies of trace gas exchange processes. Deployment of either a steady-state or non-steady-state chamber inherently perturbs its underlying vertical and horizontal soil gas concentration gradients, thereby altering the surface-atmosphere gas flux that the chamber was intended to measure. Failure to understand and account for that perturbation results in the potential for significant error in estimating the true trace gas flux.

APPROACH: We are using a numerical gas diffusion model to examine steady-state and non-steady-state chamber feedback processes as a function of atmospheric interfacial layer depth, chamber headspace mixing, soil transport properties, and trace gas source/sink characteristics. It differs from other models used to investigate chamber performance in that it is 3-dimensional, uses a shorter time step, and specifically includes the chamber headspace in the simulated domain. We also developed a nonlinear regression approach to trace gas flux estimation from non-steady-state chamber concentration data that employs a recently derived analytical solution of the 1-dimensional time-dependent gas diffusion equation.

RESULTS: We built new non-steady-state chambers using design criteria established in previous simulations. The chambers were used to measure soil-atmosphere CO_2, NO_x, and N_2O emissions from mixed grass prairie under three different grazing management schemes during the 1997 growing season at the High Plains Grassland Research Station (HPGRS) near Cheyenne, WY. The results generally confirmed predictions of our simulation model regarding the dependence of chamber performance on soil transport properties, pre-deployment atmospheric interfacial layer depth, and the intensity of headspace mixing. Performance was also consistent with the model prediction that a chamber-induced change in air mixing processes operating near the soil surface causes either rapid enhancement or rapid suppression of the pre-deployment gas exchange rate, depending on whether headspace mixing is more or less efficient than predeployment conditions. Completing this work was delayed by a heavy commitment to establishing the field studies at HPGRS (reported elsewhere).

FUTURE PLANS: Model predictions that could not be tested in the field will be addressed using apparatus for generating a constant gas flux in a controlled environment in the laboratory when field work is complete. In addition, we will use data accumulated during the growing season to compare our nonlinear regression approach to traditional linear and nonlinear techniques for flux estimation from non-steady-state chamber concentration data.

SOIL NO_x AND N_2O EMISSION PULSING: MECHANISMS AND MODELING

Principal Scientists: G.L. Hutchinson, W. Yang
Cooperating Scientists: H. Skinner, G.E. Schuman
ARS/GCRP: Research Area I, Program Element B, Objective 3, Tasks 1, 4, 8
CRIS Number: 5402-11000-004-00D

PROBLEM: NO_x and N_2O are important trace atmospheric constituents involved in both global climate change and stratospheric ozone depletion. Soil is recognized as a major source of both gases, but little is known about specific production/consumption mechanisms or the confounded effects of various environmental factors on their exchange rates. A large pulse of NO_x and N_2O emission often follows wetting of very dry soil. The pulse is too large to be explained by water's well-defined effects on transport in soil, and its cause remains unclear. Emission rates during such an event are many fold higher than rates preceding or following the pulse, so the quantity of soil N lost during its brief duration may exceed the total amount emitted during the much longer time required for the soil to dry enough to support another pulse in response to the next wetting event.

APPROACH: Non-steady-state chambers are used to measure the soil-atmosphere exchange of NO_x and N_2O from three sets of plots on mixed grass prairie near Cheyenne, WY. All three sets include two grazing management schemes -- continuous heavy grazing (CH) and an exclosure (EX). Gas exchange from EX1 and CH1 plots will be monitored weekly for two years. Exchange from adjacent EX2 and CH2 plots will be monitored weekly for 4-6 weeks prior to destructive sampling to determine soil NH_4^+, NO_3^-, pH, bulk density, microbial biomass, nitrifier activity, and mineralizable C and N. Soil temperature and water content are monitored continuously. The third set of plots (EXIR and CHIR) receive supplemental weekly irrigation to bring total precipitation to about 2 cm per week; their exchange rates are measured just before and 2 hours after irrigation.

RESULTS: We observed the following trends: The first irrigation was followed by a large NO emission pulse (as much as 21.8 ng N m^{-2} s^{-1}) about 10-fold greater than preceding rates; pulses following subsequent irrigations had somewhat reduced intensity and duration (3-5 fold increase). The NO flux from non-irrigated plots was generally 3-5 ng N m^{-2} s^{-1}. A small post-irrigation pulse of N_2O often occurred from CHIR, but not EXIR plots. NO and N_2O emissions were similar within EX1 and EX2 plots, but there was not good agreement between the two sets. Conversely, the NO flux from CH1 and CH2 was much greater than the N_2O flux, and there was good agreement between the two sets for both gas emission rates. A large pulse of both gases occurred from non-irrigated plots of both grazing treatments following heavy late-July precipitation that fell on very dry soil. The pulse was smaller from CHIR and EXIR plots, probably because weekly irrigation prevented the buildup of substrate required to support trace gas emission pulsing.

FUTURE PLANS: Field measurements of NO and N_2O flux will continue for two years. Also, in controlled laboratory soil incubation experiments we will use selective microbial inhibitors and independent manipulation of the concentrations and transport rates of gas-phase and solution-phase reactants and products of microbial C and N transformations in soil to characterize the contributions of these and other processes to pulse events. Finally, we plan modeling studies to quantify the effect of precipitation/irrigation on NO and N_2O emission pulsing and to enhance understanding of the mechanisms involved in production/consumption of the two gases in soil.

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METHANE, NITROUS OXIDE AND NITRIC OXIDE FLUXES IN THE COLORADO SHORTGRASS STEPPE

A.R. Mosier - Coinvestigators W.J. Parton [1], D.S. Ojima [1], D.S. Schimel [2]

Project Number: 5402-11000-005-00D

PROBLEM: Knowledge of the role of agricultural and rangeland systems on the atmospheric concentrations of trace gases CH_4, N_2O, and NO_x is limited. Since these gases are involved in local and regional atmospheric oxidant concentrations, global atmospheric warming and stratospheric ozone depletion, understanding of the impact of land management and land use change on the soil-atmosphere exchange of these trace gases are needed to understand the changing atmospheric concentrations of these trace gases and to provide research based information to local, regional, national and international policy makers.

APPROACH: In 1990 a program was initiated to measure the soil-atmosphere exchange of CH_4 and N_2O in a variety of systems within the Colorado shortgrass steppe and other regional and more widespread ecosystems. In 1994 quantification of NO_x fluxes was integrated into the program. The program will continue as an integral part of the shortgrass steppe long term ecological research program (NSF/LTER) and earth observation system (NASA/EOS) and data are being incorporated into the data sets being accumulated by the U.S. Trace Gas Network activity that are being used in modeling the local, region and global impact of trace gases.

RESULTS: From our measurement program we have assessed intersite, interannual variations in trace gas fluxes in the shortgrass steppe. We found that wintertime fluxes contribute 20-40% of the annual N_2O emissions and 15-30% of CH_4 consumption at all of the measurement sites. Nitrous oxide emission maxima were frequently observed during the winter and appeared to result from denitrification when surface soils thawed. Generally, site mean annual flux maxima for CH_4 uptake corresponded to minimum N_2O fluxes and vice versa, which supports the general concept of water control of diffusion of gases in the soil and limitations of soil water content on microbial activity. We also observed that pastures that have similar use history and soil texture show similar N_2O and CH_4 fluxes, as well as similar seasonal and annual variations. Sandy loam soils fertilized with nitrogen 5-13 years earlier consumed 30-40% less CH_4 and produced more N_2O than unfertilized pastures. In contrast, the N addition 13 years earlier does not affect CH_4 uptake but continues to increase N_2O emissions in a finer-textured soil. We found that conversion of grassland to croplands typically decreased the soil consumption of atmospheric CH_4 and increased the emission of N_2O. Fields converted to winter wheat production about 70-y earlier consumed about 50% less CH_4 produced about double the amount of N_2O than the native grassland. A wheat field that was reverted back to grassland in 1987 continued to exhibit annual CH_4 uptake and N_2O emission rates similar to the wheat fields. Another wheat field that was returned to grassland in 1939 exhibited the same CH_4 and N_2O flux rates as comparable native pastures.

FUTURE PLANS: The long term studies to further understand N biogeochemistry and interannual variability of trace gas fluxes within the shortgrass ecosystem will continue.

NREL, Colo. St. Univ.[1]; NCAR, Boulder, CO[2].

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SHORTGRASS STEPPE ECOSYSTEM DYNAMICS AND TRACE GAS EXCHANGE UNDER ELEVATED CO_2

A.R. Mosier and J.A. Morgan- Coinvestigators: W.J. Parton, D.S. Ojima and D.G. Milchunas*

Project Number: 5402-11000-005-00D

PROBLEM: Atmospheric CO_2 concentrations have been rising in the past few decades at historically unprecedented rates, and are projected to continue rising. No field studies have addressed how elevated CO_2 might impact the shortgrass steppe of the western United States. Based on experiments in other ecosystems, elevated CO_2 is expected to initially enhance short-term productivity of the grassland. In the long-term, CO_2 enrichment may elicit significant soil microbiological responses that will determine the capability of the grassland to respond to CO_2. The CO_2-induced alterations in soil microbial activities will also affect the exchange of CH_4, NO and N_2O within the grassland in unknown ways.

APPROACH: Funding was obtained from the Interagency Terrestrial Ecology and Global Change Initiative to begin research which couples the use of large, open-top chambers for field CO_2 enrichment studies with soil N cycling and trace gas flux measurements. The basic objectives in this research are to determine the impact of doubling CO_2 in the SGS on (1) photosynthesis, productivity, water and N use efficiency, plant water relations, and C and N allocation in above- and below-ground organs of two dominant grass species, a C_4 and the other a C_3 species; (2) soil water and N dynamics; and (3) fluxes of CO_2, CH_4, NO_x and N_2O. Knowledge gained from the studies will be incorporated into simulation models that will allow for realistic extrapolation through time and space of soil moisture, nutrient cycling, plant productivity, and overall ecosystem response.

RESULTS: During the past year the open-top chamber systems were constructed and tested so that CO_2 enrichment began in the spring of 1997. During the construction period we conducted several experiments and sets of measurements to use as baseline information and to test the effect of a the small N addition planned for the CO_2 enrichment study sites so that system N utilization could be quantified. We found, from additions of 0.5 g N m^{-2} of ammonium nitrate, that this rate of N addition neither altered the emission rates of NO or N_2O nor the rate of soil consumption of atmospheric CH_4 through a 6-month measurement period. The peak standing biomass of the three major grass species within our study sites across the different CO_2 enrichment locations were not distinguishably different at the start of the study. About three months after beginning CO_2 enrichment, peak standing biomass was significantly higher in the CO_2 enriched chambers.

FUTURE PLANS: The CO_2 enrichment study began in the spring of 1997. We anticipate continuing the study for at least 5 years after initial enrichment.

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*Natural Resource Ecology Laboratory and Rangeland Ecosystem Science, Colo. St. Univ.

North American Trace Gas Network (TRAGNET)

A.R. Mosier--Collaborators: D.S. Ojima[1], W.J. Parton[1] and the TRAGNET Steering Committee

Project Number: 5402-11000-005-00D

PROBLEM: Many trace gas research programs are being conducted in North America. Data is being collected in a wide variety of ecosystems that could be used to answer regional and global questions concerning trace gases. Currently much of the information is fragmented and is not readily accessible by the scientific community as a whole and models developed to describe trace gas fluxes are largely untested because of this fragmentation.

APPROACH: The U.S. Trace Gas Network (TRAGNET) has begun to assemble trace gas field data and models to facilitate intercomparison of data sets and models from around the world. TRAGNET has been funded by the U.S. National Science Foundation to assemble, organize, and synthesize trace gas flux data from a range of ecosystems. TRAGNET is a consortium of research groups with three overall objectives: (1) to document contemporary fluxes of trace gases between regionally important ecosystems and the atmosphere; (2) to determine the factors controlling these fluxes; and (3) improve our ability to predict future fluxes in response to ecosystem and climate change. To accomplish this, TRAGNET is establishing along-term data archive for trace gas fluxes and associated data to facilitate data intercomparison between sites. TRAGNET is also coordinating a series of intercomparisons of trace gas models for these various field sites; this serves both to promote interaction between modeling and measurement groups, and to foster development of robust trace gas flux models.

RESULTS: The first TRAGNET multi-site, multi-model intercomparison of N_2O fluxes was begun in 1996. Three temperate agricultural field sites with completed year-round N_2O flux measurement programs were chosen for the study: an unfertilized semiarid rangeland in eastern Colorado; a fertilized grass ley cut for silage in Scotland and two fertilized cultivated fields in Germany. Four models were included in the first intercomparison: CASA, CENTURY-NGAS, ExpertN and DNDC. These models included similar components (soil physics, decomposition, plant growth, and nitrogen transformations) and generated similar results for the general cycling of nitrogen through the agro-ecosystems. They did, however, simulate nitrogen trace gas fluxes very differently.

FUTURE PLANS: Expansion of the trace gas flux and model data bases is focused to prepare for a workshop for the analysis and synthesis of trace gas fluxes that is to be held at the National Center for Ecological Analysis and Synthesis in December, 1997. At this workshop a group of data collectors and modelers will assemble to conduct a series of intercomparisons across a large variety of ecosystems, tropical to boreal. These efforts are being expanded to further development of our capability to predict future fluxes in response to ecosystem and climate change.

[1]Natural Resource Ecology Laboratory, Colo. St. Univ.

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GLOBAL CHANGE AND BELOWGROUND PROCESSES IN AGRICULTURAL SYSTEMS

H. H. Rogers, S. A. Prior, H. A. Torbert, D. W. Reeves, R. L. Raper, D. C. Reicosky, D. E. Stott, **ARS**‖G. B. Runion, G. L. Mullins, **Auburn**‖R. J. Mitchell, **Jones Ecol. Res. Ctr.**‖W. A. Dugas, **Texas A & M**‖J. S. Amthor, **Oak Ridge**‖J. L. J. Houpis, **Southern Illinois**‖C. M. Peterson, **Northern Colorado**‖H. BassiriRad, **Illinois**‖ S. V. Krupa, **Minnesota**‖W. H. Schlesinger, **Duke**

CRIS: 6420-11000-001-00D

PROBLEM: The global environment is changing and it is evident from an incontestable data base that CO_2 within the atmosphere has risen substantially and, in all probability, will continue to rise. The most noted consequence, albeit uncertain, of this increase are predicted shifts in Earth's climate. Perhaps this high degree of uncertainty is the most important reason for in-depth exploration of the question. Regardless of the eventual outcome of the climate issue, vegetation will be directly affected by the increased concentration of atmospheric CO_2. This increase in CO_2 has led to many uncertainties associated with Earth systems. Concerns encompass indirect effects related to predicted shifts in climate and direct effects on the biosphere, mainly terrestrial plant systems, crops being a chief concern. Plant growth is often stimulated when CO_2 concentrations rise and the stimulation of root development immediately leads to hypotheses of shifts in rhizosphere microbiology and soil processes. Enhanced plant growth further suggests greater delivery of C to soil, and thus potentially more soil C storage. However, little research has focused on belowground responses in agricultural systems.

OBJECTIVES: Reduce uncertainty regarding: (1) the effects of rising atmospheric CO_2 concentrations on crop production and food security, and (2) the role of agronomic systems in the sequestration of atmospheric CO_2 as organic carbon in soils, as affected by tillage systems, crop rotations, and production practices. Specific objectives include the determination of CO_2-induced effects on belowground processes which affect crop productivity, soil properties, and carbon/nutrient cycling. Effects of rising CO_2 levels on root structure and function, and the interactions between crop roots, soil microorganisms, and soil organic carbon will also be documented.

FUTURE PLANS/APPROACH: We are in the initial stages of installing a new six year comparative study of a "conventional" tillage system without winter cover crops and a "sustainable" system with minimum tillage and winter cover crops. Crop rotations include grain sorghum (*Sorghum bicolor* L. Moench), soybean (*Glycine max* L. Merr.), wheat (*Triticum aestivum* L.) and crimson clover (*Trifolium incarnatum* L.)]; the soil is a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults). Work will take place at soil bin facilities of the ARS-USDA National Soil Dynamics Laboratory. There are three objectives: (1) Determine effects of elevated atmospheric CO_2 on plant roots (structure and function), rhizosphere microbiology (activity and populations), and soil properties (chemical and physical). (2) Quantify the cycling of carbon (including sequestration potential) and nutrients (including implications for groundwater quality) in CO_2-enriched agricultural systems. (3) Develop new methodologies for belowground research, with provision for assessment of atmospheric composition, temperature, and water, nutrient, and carbon dynamics.

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Report of Progress

Trace Gas Emissions from Agricultural Cropping Systems: Soil, Plant, and Animal Production (Ammonia Emissions from Swine Lagoons)

Lowry A. Harper and Ron R. Sharpe

ARS GCRP: Res. Areas: 1; Prog. Elements: B; Objs: 3; Tasks: 1,8.
CRIS Numbers: 6612-13610-001-00D
6612-12000-008-00D

Problem: Seventy-five percent of swine production systems in North America use anaerobic or liquid/slurry systems for waste holding or disposal. Because of increased production efficiency and economics and a better industry support system, production is concentrated into relatively small regions causing potential problems of waste disposal and natural (ecological) system absorption of excess nutrient byproducts to the surface water, groundwater, and to the atmosphere. In order to evaluate the effect of animal concentrations on the regional soil, surface and ground waters, and atmospheric environments, accurate emission factors are needed by planning and regulatory agencies. Emission factors, developed mainly in northern Europe, are variable and questionable for use in the subtropical to temperate regions of the United States. Measurements made in the United States have also been variable ranging from zero to over 500 kg NH_3 animal^{-1} y^{-1}. Emission factors for methane and nitrous oxide are equally as variable because of the use of inappropriate methodology or inadequate sensitivity of analytical equipment. The purpose of these studies is to use techniques to evaluate radiatively active trace and other gases without disturbing the plant, animal, or management system being measured.

APPROACH: Micrometeorological techniques for non-interference measurements include gradient diffusion, micrometeorological mass difference, and isotopes. For measurement of trace gases over large lagoons, the gradient diffusion (specifically the momentum balance) technique was determined most appropriate but new equipment was designed for instrumentation and sampling. Meteorological and gas-sampling equipment were constructed on a pontoon barge which was floated to the center of the lagoon. Adjustable legs were extended to the solid bottom and the barg was sunk to just below the water surface to eliminate to reduce aerodynamic resistance by the structure. Trace gas concentration measurement included tunable diode laser spectroscopy, infrared gas analysis, and gas-washing techniques. Aerosols were measured using microfilters. Corollary measurements included climatic (windspeed, air and water temperature, radiation) and lagoon (nutrient content; pH; methane potential; dissolved oxygen, methane, nitrous oxide, and carbon dioxide; and sludge depth) measurements. Where lagoon effluent was land-applied, soil and plant measurements were made.

FINDINGS: Ammonia emissions varied diurnally and seasonally, from low emissions during winter and low windspeeds and high emissions during summer and high windspeeds. The highest correlation was with nutrient concentration followed by water temperature. Most of the variability in emissions (r^2=0.94) was explained by water ammonium concentration, temperature,

pH, and windspeed. Nutrient loading of the lagoon system was measured which showed the largest percentage of nutrients accumulated in the first of four successive lagoons. Mobile ions which were non volatile (potassium, sodium) were constant in concentration throughout the four lagoons in both the effluent and in the sludge layer. Immobile ions (phosphorous, organic nitrogen, calcium, sulfur, magnesium, zinc, iron, manganese, copper) concentrated primarily in the sludge layer of the first lagoon (enrichments in the first lagoon ranged from five to a thousand [zinc] times higher than in the secondary lagoons). Nitrogen decreased in concentration from about 1400 ppm in the sludge layer of the first lagoon down to less than 50 ppm in the fourth lagoon. Measurements were made for a partial nitrogen mass balance, and nitrogen removal pathways included ammonia emissions (32%), retention in the sludge layers (12%), seepage (13%), and irrigation onto cropland (2%). Unaccounted for nitrogen was 40% of the input. Speculated other losses included denitrification in the third and fourth lagoons (to nitrogen gas--no nitrous oxide gas was measured) and ammonium aerosols. Mass balance for all other nutrients were evaluated.

FUTURE PLANS:

1. There is no accurate estimate of methane, nitrous oxide, and ammonia emissions from dung under pasture conditions. Using the micrometeorological mass difference technique, measure radiatively-active and other trace gases from grazing cattle.
2. Measure methane fluxes from a swine lagoon during the warm (summer) season.
3. Measure radiatively-active and other trace gases in secondary waste lagoons.
4. Measure ammonia emissions and lagoon-nitrate denitrification in secondary waste lagoons.
5. Nitrogen mass balance in animal rearing barns including feed input, animal nutrient retention, and ammonia loss.
6. Lagoon ammonia emissions to the atmosphere (about 18,000 kg ha^{-1} $year^{-1}$) must be absorbed into surrounding natural ecosystems. Absorption into surrounding grass/pine-tree ecosystems will be measured using flux-gradient techniques and new laser spectrometry for gas analysis.
7. A carbon balance will be made on the lagoon system to attempt to evaluate methods by which methane emissions may be reduced.

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Carbon Sequestration in Corn-Soybean Agroecosystems

R.R. Allmaras and C.E. Clapp
Soil and Water Management
439 Borlaug Hall, University of Minnesota
St. Paul, MN 55108

D.R. Huggins, Land Management/Water Conservation Research
Pullman, WA 99163

Cooperating Scientists: *J.A. Lamb*, University of Minnesota, St. Paul, MN.

ARS Global Change Research Program: See description of Research Areas, Program Element Objectives and Tasks in Appendix A. (in Global Change and Agriculture: Soil, Water, and Plant Resources. Volume II: Program Details and Research Reports. USDA-ARS. May 1996).

Research Areas:	I			IV
Program Elements:	B		D	A
Objectives:	1	2	1	2
Tasks:	3	3	3	1

CRIS Numbers: 3640-12000-005-00D
5348-12000-006-00D

Problem

Sequences of corn and soybean dominate in the Corn Belt and comprise a large part of cultivated land in the United States. Few studies have focused on organic matter dynamics and C sequestration in this agroecosystem, where large amounts of biomass are produced annually, tillage systems may vary yet some incorporate large amounts of crop residue, the soils can remain wet for extended periods of time, and a C3 crop (soybean) is normally rotated with a C4 crop (corn).

Approach

Soil samples from long-term experiments are being subjected to physical and chemical analysis, including $\delta^{13}C$ isotope analysis. Many experiments have been used for in situ physical measurements to describe crop residue interactions/ incorporation, crop residue production, crop rotation effects, and crop rooting. Soil mechanical, thermal, and hydraulic properties have also been measured in these soils and experiments.

In the Corn Belt there are numerous long-term field experiments involving corn-soybean-oats (C3) sequences compared with

continuous monocropping. Field experiments are either corn-soybean or corn-oats, which facilitates $\delta^{13}C$ isotope analysis to trace the C3 and C4 origin of the C isotope ratio. Some experiments have long-term residue return or removal, as well as induced changes in pH due to N fertilization. Some experiments compare tillage systems with a wide spectrum of positioning crop residue on the surface and within the Ap layer.

Physical-based fractionation systems in water are being used to evaluate interactions of soil structural and C cycle/ retention as related to tillage systems, individual crop species and cropping sequences of corn and soybeans (C4 vs. C3). By use of C and N concentrations as well as the ^{12}C:^{13}C, attempts will be made to describe the short term cycle in the presence of the long-term cycles of C.

Findings

Soil samples from the 0 to 15 and 15 to 30-cm layers of a Webster clay loam collected in 1991 from a long-term experiment with 15 crop sequence treatments were subjected to total soil organic C, (SOC), total N, and $\delta^{13}C$ analysis. Total SOC was similar across all treatments after 10 years even though residue return from corn was 1.5 times that from soybean. Significant differences in soil $\delta^{13}C$ between continuous corn ($\delta^{13}C = 17.2‰$) and continuous soybean ($\delta^{13}C = -18.2‰$), and larger $\delta^{13}C$ with depth in the Ap layer were produced by isotopic discrimination during microbial decomposition. A two-pool carbon model showed SOC decay rates of 0.011 and 0.007 yr^{-1} for C4- and C3- derived C — both are slightly lower than in other Corn Belt studies. Humification rates were 0.16 and 0.11 yr^{-1} for corn and soybean respectively. SOC could decline an additional 15% using current C inputs with moldboard tillage of this poorly drained soil.

Soil samples from selected sequences were subjected to increasing levels of energy in water to analyze for aggregate hierarchy and location of the $\delta^{13}C$ labeled organic matter. Fractionation in water shows a differential carbon affinity for soil fractions; soybean derived C had more affinity for the coarse fractions while corn derived C had more affinity for the fine fractions. Carbon recovery in the fractionation ranged up to 94%; a particulate organic fraction recovered was about ½ of the annual return with 82% purity in continuous corn and 72% purity in continuous soybean. Staging of physical energy input into wet soil systems indicates more than 10 years to alter $\delta^{13}C$ of the $<53\mu$ fractions, but the different sequences did influence C content and $\delta^{13}C$ in the $>53\mu$ fractions.

Future Plans

Additional field experiments with crop sequence and tillage x crop sequence have been sampled and whole soil analyses are underway from Lamberton (Normania-Ves), Waseca (Webster-Nicollet), and Rosemount (Waukegan) soils. Publication of the initial experiments is underway.

Publications since 1995:

Huggins, D.R., R.R. Allmaras, C.E. Clapp, and J.A. Lamb. 1995. Carbon sequestration in corn-soybean agroecosystems. Pages 61-68 *in* R. Lal, J. Kimble, E. Levine, and B.A. Stewart, (eds.). Soil Management and Greenhouse Effect. Adv. Soil Sci. Series. Lewis Publishers, Boco Rotan, Fl.

Huggins, D.R., C.E. Clapp, R.R. Allmaras, J.A. Lamb, and M.F. Layese. 1998. Carbon dynamics in corn-soybean sequences as estimated from natural C-13 abundance. Soil Sci. Soc. Am. J. 62:(in press).

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Soil-C storage in arable lands of United States as related to crop residue and tillage

R.R. Allmaras, Soil and Water Management
439 Borlaug Hall, University of Minnesota
St. Paul, MN 55108

D.E. Wilkins, Soil and Water Conservation Research
Columbia Plateau Conservation Research Center
Pendleton, OR 97801

Cooperating Scientists: *O.C. Burnside* and *D.J. Mulla*, University of Minnesota, St. Paul, MN.

ARS Global Change Research Program: See description of Research Areas, Program Elements, Objectives and Tasks in Appendix A (in Global Change and Agriculture: Soil, Water, and Plant Resources. Volume II: Program Details and Research Reports. USDA-ARS. May 1996).

Research Areas:	I	IV	V
Program Elements:	B	A	A
Objectives:	2	2	1
Tasks:	3	1	1

CRIS Numbers: 3640-12000-005-00D
5356-12000-006-00D

Problem

The soil organic carbon (SOC) pool is estimated to be about ⅔ of that in the terrestrial biosphere, and the estimated annual exchange is about 4% of the soil organic carbon pool or 8% of the atmospheric pool (Schlesinger, 1995). The mean half-life of C in the SOC pool is estimated to be 32 years. The SOC pool was anthropogenically reduced from 20 to 40% reaching a near steady-state low in about 1940 in arable agriculture — conversion of grasslands to arable agriculture had already ceased in about 1910. This is also the era when unit crop yields were low and stagnated (Allmaras et al., 1997). A 1% decrease in the evolution of CO_2 from SOC would be equivalent to 14% of the fossil fuel perturbation (Schlesinger, 1995). A recent analysis by Kern and Johnson (1993) suggests that net SOC sequestration will not be positive until about 2010, when no-till will be used on 80% of US arable land. A somewhat different approach (Allmaras et al. 1997) indicates that net SOC sequestration had already become positive in about 1975.

Approach

Trends in the national unit-area harvest yields of most cash crops and changes in harvest index along with harvest yields indicate changes in crop residue return. Tillage-planting systems used by American farmers have changed dramatically since about 1975. The change in SOC sequestered in long-term field experiments shows large differences in favor of the tillage systems now being used in arable cultivation.

Findings

Unit-area harvest grain yields for seven major crops of the US remained stagnated until about 1940 — the growth of yield from 1940 to 1990 ranged about 75% (for oats) to 440% (for corn). Meanwhile the harvest index increased about 45% for all crops. The net change in C in crop residue (shoot plus root) increased about 10% (soybean) to 120% (corn). C returned in small grain increased about 80% in the same 1940-to-1990 period. During this period there were also marked changes in the harvest methods to prevent microsite losses. Buyanovsky et al. (1996) show that a larger residue return using the same moldboard system has shown some recovery of SOC from the low levels of 1940. Best estimates are that the moldboard plow was used on 80 to 90% of tilled land until about 1975— use of a stubble mulch system in semiarid lands did not start until about 1950. Surveys (ERS, 1994) in 1994 show only about 4 to 9% of planted wheat, soybean, and corn receives moldboard primary tillage — all other systems use a disk, chisel, or sweep for primary tillage (some no tillage) to maintain crop residue above 10 cm soil depth and on the surface.

Comparisons of long-term tillage systems show a maintenance/increase of SOC with tillage systems that use chisel, sweep, or disk for primary tillage, a general increase with no-till systems, and a marked decrease with moldboard based systems. While the difference among systems that maintain crop residue above 10 cm are usually small, this group always differs markedly from the moldboard-based system.

The above three trends in arable agriculture show that farmers already have achieved a positive SOC balance; this likely occurred about 1980.

Future Plans

Although the structure of this analysis has been developed, there is a need to evaluate the literature for changes in SOC preceding 1970 to show that moldboard plowing might have prevented responses to more residue return, and to evaluate in more detail the SOC changes brought about by long-term tillage comparisons as they relate to current farm use. A determination of the other benefits from the large residue return and recent tillage-systems changes could help to focus on sustainability of an SOC accretion.

Publications:

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Strategic Plan Issue

Establishing soil carbon pool sizes and fluxes from soil organic matter turnover

D.C. Reicosky
USDA, ARS, MWA, Morris, Minnesota

CRIS: 3645-11120-003-00D

PROBLEM: Greenhouse gas concentrations in the atmosphere are steadily increasing. The recent concern for stabilizing of greenhouse gases in the atmosphere to minimize climate changes is important to the environment. Soil organic matter is known to act both as a source and a sink for global CO_2 and is equally important in biological productivity of managed and unmanaged systems. By increasing soil organic matter in crop production systems, agriculture may contribute to alleviating global greenhouse warming.

APPROACH: Management of crop residues and soil organic matter are important in maintaining soil fertility and productivity and for minimizing agriculture's impact on environmental change. With low soil carbon, tillage becomes more difficult and costly. Intense tillage systems have been known to result in a significant decrease in soil organic matter in nearly all agricultural production systems. Conventional tillage methods using the moldboard plow are declining due to energy costs and potential soil erosion, and the recently identified tillage-induced loss of CO_2. There is optimism that intense agriculture through the increased production of grain and biomass will lead to increased sequestration of soil C and have positive benefits on soil organic matter. Many long-term studies demonstrate increases in soil C levels are in proportion to increased residue inputs. An earlier study covered stover-fertility management of continuous corn for 13 years in which there were two stover treatments, one total stover removal as silage, and second stover plowed down after grain harvest. This experiment was maintained a total of 30 years and provided an opportunity for evaluating tillage-induced CO_2 loss and soil C levels. The recent findings of tillage-induced CO_2 losses following the moldboard plow and the long-term nature of this study provided an opportunity to gather more information on the potential impacts of extreme residue management on total soil C. Thus, the specific objective of this work was to evaluate the impact of 30 years of continuous corn silage removal vs. grain removal at low and high fertilities on the tillage-induced CO_2 loss and total soil C and N levels.

RESULTS and INTERPRETATION: Tillage-induced CO_2 loss was measured using canopy gas exchange after moldboard plowing in the spring of 1996. Soil C and N analysis were done using standard analytical techniques. The 24-h cumulative CO_2 loss differences were not significant between treatments with annual silage or grain removal and showed no fertility effects. After 30 years, total C or N or the C:N ratios remained virtually unchanged. All four treatments had the same organic C content of 21.9 g kg^{-1} in the 0-15 cm depth after 30 years. The cumulative total of 217 Mg ha^{-1} of aboveground stover from the high fertility grain treatment compared to none from the high fertility silage treatment yielded no differences in total organic C. Twice as much fertilizer N had no effect on total C or C:N ratios. These results suggest intensive tillage by moldboard plow caused rapid organic matter decomposition that masked fertility effects on total C. Residue removal or addition had no affect on soil carbon that continued to decrease with

moldboard plowing. Agricultural production systems need new approaches to enhance C sequestration with less tillage before there can be a positive increase in soil organic matter.

FUTURE PLANS: We will continue to pursue the impact of various tillage methods on the short-term CO_2 release in various cropping systems. Current emphasis is on evaluating various forms of strip tillage and soil reconsolidation on gas exchange. Plans include evaluating the effect of till-plant and secondary tillage equipment on the amount of CO_2 lost. We plan further testing of pressure effects within the chamber to determine the impact of turbulent mixing on the CO_2 fluxes and the effect of pH on the solubility of CO_2 released after tillage. Changes in soil air permeability from tillage at large scale combined with convective flow forces are being explored to extrapolate results to watershed scale.

USDA, ARS, MWA NORTH CENTRAL SOIL CONSERVATION RESEARCH LAB

Publications

Reicosky, D.C. 1996. Impact of tillage methods on water and carbon dioxide dynamics. pg. 442-443. *In:* R. Ishii and T. Horie (eds.) Crop Research in Asia: Achievements and Perspective. Proc. 2nd Asian Crop Sci. Conf., Fukui, Japan.

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HYDROLOGIC PROCESSES

HYDROLOGICAL PROCESSES

Final Report of the Hydrology Group

Proposed locations for future workshops:

Ft. Collins (late 1998)
Southeastern U.S.
Beltsville

Recommendations for Improved Interactions Among Sub Groups:

- Open workshop with a half-day session of poster presentations by all three groups to facilitate one-on-one interactions.
- Have a meeting of group coordinators and NPS leaders about six months before the next workshop for planning purposes.
- At the next workshop, have break out sessions to promote subgroup interactions. Pre-established themes need to be decided upon before the workshop. Possible themes could include large scale experiments; rivers out of control; projects in new areas of the U.S., etc.

Other Workshop Activities:

- Have program scientists from other agencies present their programs at our Global Change Workshop.
- Present our accomplishments in a symposium-like atmosphere. Hold a workshop to assess our original planned research accomplishments and develop a new "5 year" global change research plan. Time scale: next 2-3 years.
- Location tour at beginning or end of workshop for those who really want to go.

HYDROLOGICAL PROCESSES

Summary of Location Reports

What are we doing to estimate climate change effects on water supplies and water quality?

- Use models and climate change scenarios (from GCMs) to estimate hydrologic response under conditions of climate change.
- Use long term and large area data sets to assess changes in hydrologic processes and relationships.

Currently Available Deliverables

- Models - TOPAZ, SWAT, EPIC, ALMANAC, SRM, WEPP, CLIGEN, WGEN, USCLIMAT, SHAW, ERHYM.
- Databases - U.S. National Assessments Database, Monsoon 90, Plant/Soil/Water Database (Boise), SURFRAD, ARS Watershed Databases.

The information generated from this approach is available to water resources managers for developing management strategies for mitigating and adapting to climate changes.

All groups have research ongoing that will result in additional deliverables in the next several years.

Climate Change Modeling Studies

Principle Scientist: Jeff Arnold

Cooperating Scientists: Clarence Richardson, Jim Kiniry, Kevin King

ARS GCRP: Research Area I, Program Element A, Objective 1, Task 4

CRIS Numbers: 6206-13610-001-00D, 6206-13610-002-00D

Problem/Approach: A modeling approach is one means available to study the long term impacts of global climate change on regional water supplies. The selected approach is to integrate climate change capabilities into existing comprehensive hydrologic and water quality models. Climatic variables considered in the models include precipitation, temperature, wind, solar radiation, humidity, and CO_2. Output response variables include plant biomass, crop yields, stream flow, water supply and water quality. The models were modified (Stockle et al., 1992) to simulate the effects of atmospheric CO_2 on radiation use efficiency and ET using the Penman-Monteith method. Models developed and supported at Temple are divided by spatial scale. The field scale model, EPIC, has been used extensively to model the potential impact of climate change on crop yields. At the watershed/river basin scale, a model called SWAT is being used to assess the impact of climate change on hydrology and regional water supplies.

Findings/Assessments:

EPIC - Field Scale Regional Assessment

- USEPA - EPIC was used to simulate the impact of elevated CO_2 on corn and soybean yields in the Midwest.
- Resources For the Future (RFF) - Utilized EPIC to simulate crop yield response to temperature, precipitation and CO_2 in the Midwest.
- Battelle Pacific Northwest Laboratory - Expanded the RFF study from the Midwest to the entire United States.

SWAT - Watershed / River Basin Scale Assessment

- Potsdam Institute for Climate Research - Applied SWAT to the Elbe River Basin in Central Europe (96,000 sq km) to assess the impact of climate change on water supplies (Krysanova et al., 1996).
- Department of Energy - Funding a project "Water Resources and Climate Change in the Missouri River Basin". The following universities are

participating in the project (Hotchkiss et al., 1996).

- University of Nebraska - Project Coordination and simulation of reservoir operation.
- South Dakota School of Mines - Model validation in the Black Hills and scaling issues.
- Montana State University - Snowmelt simulation and economic analysis.
- Texas A&M University - Database and model support.

- Battelle Pacific Northwest Laboratory - Developing a national SWAT run using GCM estimates of changes in climate variables to assess the impact on stream flow and the hydrologic balance.
- EPA - Funding the University of Minnesota to assess the impact climate change in northern forested watersheds.
- EPA - Funding the University of Illinois to assess the impact of climate change on crop yields, stream flow, and irrigation management.

Future Plans:

1. Work with the Grassland Protection Research Unit at Temple to validate and improve existing models.
2. Continue working with users in utilizing models for climate change assessment.

Publications:

Stockle, C.O., J.R. Williams, N.J. Rosenburg, and C.A. Jones. 1992. A method for estimating the direct effects of rising atmospheric carbon dioxide concentration on growth and yield of crops. I. Modification of the EPIC model for climate change analysis. Agic. Systems. 38:225-238.

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Hotchkiss, R.H., S.F. Jorgensen, R.S. Muttiah, J.G. Arnold, T.A. Fontaine, S.J. Kenner, and J.M. Antle. 1996. Impacts of climate change in the Missouri river basin. Proc. ASCE Annual Conf.

QUANTIFY RUNOFF GENERATION AND IDENTIFY DOMINANT HYDROLOGIC PROCESSES OVER A RANGE OF SCALES

Principle Scientist: D.C. Goodrich

Cooperating Scientists: L. J. Lane, D. A. Woolhiser, R. M. Shillito, C. L. Unkrich

ARS GCRP: Res. Area I; Prog. Ele. A; Objective 1; Task 5

CRIS Numbers: 5342-13610-005-00D

Problem: While the non-linear nature of watershed runoff response for a given area has long been recognized, the literature suggests that watershed response may become more linear with increasing scale due to increased averaging at larger drainage areas and dominance of response by channel flow. However, these findings result primarily from more humid regions and this observation has not been tested in arid and semiarid regions. If linearity increases with increasing basin scale rules for model aggregation can be more easily.

Approach: To investigate the effect basin scale has on runoff production, observed runoff data for 31 nested watersheds within the Walnut Gulch Experimental Watershed (150 km^2) were analyzed. The spatial characteristics of over 300 storms were examined to assess the implications of partial area storm coverage. Modeling studies to estimate peak discharge rates for various return frequencies were conducted on all primary Walnut Gulch watersheds. A more detailed mechanistic model (KINEROS) was then applied on a specified subset of watersheds to further explore the nature of runoff response as a function of basin scale.

Findings: Analysis of the runoff data for the subwatersheds within Walnut Gulch indicated a transition in the rate of change of average runoff with increasing watershed size. An examination of channel area as a function of drainage area, especially the transition of drainage swales to incised channels, indicated the dominance of channel process vs. overland flow processes may also be a function of basin size. Results of modeling 100-yr floods using the Walnut Gulch data indicated that spatial averaging of rainfall inputs to distributed models limit their performance in estimating flood frequency under the ephemeral nature of the Walnut Gulch watersheds. Additionally, runoff response in the ephemeral Walnut Gulch watersheds becomes more non-linear with both increasing watershed area and decreasing storm size. This is primarily due to the increasing effect of channel losses and associated infiltration-related threshold non-linearities, as well as to partial area storm coverage.

Future Plans: The manuscript describing this work has been accepted for publication in *Water Resources Research* and is currently in press.

Publication:

Goodrich, D.C., Lane, L.J., Shillito, R.A., Miller, S.N., Syed, K.H. Syed, and Woolhiser, D.A., Linearity of Basin Response as a Function of Scale in a Semi-Arid Watershed, *Water Resources Research,* in press.

IMPACTS OF DEM DATA FORM, TYPE & RESOLUTION ON HYDROLOGIC MODELING

Principle Scientists: D.C. Goodrich, J. Garbrecht, T. O. Keefer

Cooperating Scientists: O. Palacios, R. Grayson, G. Blousch, G. Willgoose (All non-ARS)

ARS GRCP: Res. Area: I; Prog. Elements: A; Objs: 1 and 2; Tasks: A1-7, A2-1

CRIS Numbers: 5342-13610-005-00D

Problem: A crucial link between many resource models and a GIS is spatially distributed digital elevation model (DEM) data. The three primary forms of DEM data are grid, contour and triangular irregular network (TIN) data. Each type has advantages and disadvantages for data storage and surface representation. However, a comparative evaluation of the relative advantages and disadvantages of each DEM data type for hydrologic modeling has not been conducted. In addition the assessment of type and resolutions of DEM data on a given hydrologic model have not be evaluated in a location with independently derived DEM data.

Approach: Five modeling groups have collaborated on this project with models based on TIN, contour and grid DEM data as well as on a kinematic cascade and a hybrid case. Routing cases where then developed for a simple overland flow plane, an open book geometry (2 planes to a channel) and for the simple first order R5 watershed. The first two cases were carefully contrived to establish the variation in routing among to models that is attributed to numerical implementation. Collaboration with J. Garbrecht is also occurring to modify the TOPAZ topographic analysis software to derive basin attributes and KINEROS geometric model parameter from DEM data. This will be used on 3 independently derived DEM data sets (USGS, Radar, ARS) over Walnut Gulch to quantify the impacts of DEM type and resolution on rainfall-runoff modeling.

Findings: Minor progress has been made on this project since the last report due to the demands of the SALSA Program. Several refinements to the approach were completed and the 2-D finite element method of routing has been improved to allow a greater level of discretization that is consistent with the other models. This resulted in improved volume balance errors in this method but did not substantially alter the earlier findings.

Future plans: Several additional comparisons will be carried out prior to preparation of a manuscript summarizing the group's work for submission to *Water Resources Research* (tentatively entitled "Topographic Representation Impacts on Surface Routing"). For the assessment of DEM type and resolution on modeled runoff field surveys will be completed to verify the accuracy of the DEM data. In addition the TOPAZ algorithm will be applied to the various data sets to compare the impacts on derived basin attributes. Runoff model geometries from the various DEM data sets will then be derived over several subwatersheds in Walnut Gulch to assess there impacts on model outputs over a range of observed rainfall-runoff events.

COUPLING REMOTELY SENSED DATA TO A MESOSCALE ATMOSPHERIC MODEL

Principle Scientists: J.J. Toth, D.C. Goodrich, M.S. Moran, J. Qi

Cooperating Scientists: R. Avissar, A.F. Rahman, Electric Power Research Institute

ARS GRCP: Res. Area: I; Prog. Elements: A, D; Objs: A1, A3, A4, D1; Tasks: A1-4, A1-5, A1-7, A3-1, A4-4, D1-5

CRIS Numbers: 5342-13000-003-03T via ARS/USGS/EPRI CRADA (new project, initiated 8/95)

Problem: Remotely sensed data can be used to estimate surface sensible and latent heat fluxes over broad regions. These fluxes are of concern for atmospheric global models as well as for agricultural purposes. Many existing flux-estimate techniques make inappropriate assumptions in areas of complex topography and sparse vegetation.

Approach: Remotely-sensed parameters were used to provide inputs to the RAMS (Regional Atmospheric Modeling System) model. Based on previous work, the most useful satellite data were assumed to be (1) the effective surface temperature and (2) the NDVI vegetation index. These were used to adjust the most critical inputs for the atmospheric model. In addition, the RAMS mesoscale atmospheric model was parameterized and set-up to run in near real-time for all of 1997 at a 4 x 4 kilometer resolution over the entire San Pedro Basin. Outer boundary conditions were obtained via a two-way nested approach using ETA model output. Model output at the grid cells closest to all surface observations made as part of the SALSA program were saved for comparative purposes. In addition, all boundary conditions and forcing variables were saved so assessments could be made on the value of assimilating both remotely sensed and in-situ observations.

Findings: The effective surface temperature provides the clearest and most direct link between remote sensing inputs and model outputs. The effective surface temperatures were calculated as a weighted average of the model's vegetation temperatures and bare soil temperatures. All temperatures were converted to potential values. The critical model inputs having the most impact on the effective surface potential temperature were found to be (1) the fractional cover of vegetation and (2) the moisture availability. Simulations highlighted the importance of horizontal heterogeneities (mountains) in the atmosphere as well as at the surface. The mountains blocked and diverted the airflow, they became elevated heat sources, and they modified the turbulent mixing processes. Mountain effects were found to dominate cross-border land use differences in the Upper San Pedro Basin, site of the SALSA Program.

Future plans: Manuscripts (2) are currently being developed to describe the technique for coupling remotely sensed data with model input parameters and the results of application to the 1992 set of data over the San Pedro. Comparison of the real-time model runs with 1997 SALSA observations will also be carried out in the upcoming year.

THE SEMI-ARID LAND SURFACE-ATMOSPHERE *(SALSA)* PROGRAM

Principle Scientist: D.C. Goodrich

Cooperating Scientists: S. Moran, J. Qi, J. Everitt, R. Davis, B. Goff , J. Toth (USDA-ARS); H. Arias. C. Watts (IMADES/CIDESON, Hermosillo, Sonora, Mex.); J. Shuttleworth, S. Sorooshian, T. Maddock, B. MacNish, D. Williams (U. Ariz., Tucson, AZ); R. Avissar (Rutgers U., New Brunswick, NJ); Y. Kerr (CESBIO, Toulouse, FR); L. Hipps (Utah St., Logan, UT); A. Chehbouni (ORSTOM/IMADES, Hermosillo, Sonora, Mex.); D. Cooper (Los Alamos Nat. Lab.)

This constitutes a core group of scientists involved in the 1997 activities. However over 30 additional scientists were involved in various aspects of the project.

ARS GRCP: Res. Area: I, V; Prog. Elements: I-A, V-B; Objs: I.A.2, I.A.3, V.B.1; Tasks: I.A.2.2, I.A.3.4, V.B.1.1

CRIS: 5342-13000-003-00D

Problem: *SALSA* is a multi-agency global change research effort led by the USDA-ARS, Southwest Watershed Research Center (SWRC). It consists of a long-term research, monitoring and modeling effort. The primary question that SALSA addresses is: What are the consequences of natural and human induced change on the water balance and ecological diversity of semiarid basins at event, seasonal, interannual, and decadal timescales?

Approach: *SALSA* has completed a successful year of field experimentation and data collection. During FY 97, ***SALSA*** scientists continued ongoing studies of the upper San Pedro River watershed and implemented new studies focusing on evapotranspiration and aquifer processes within the riparian corridor (USA) and energy-balance and ecological modeling in the uplands (Mexico). The principle findings and accomplishments of the ***SALSA*** program during FY 97 are outlined below.

Findings:

1. **Collaboration and Cooperation**. Key to ***SALSA's*** success has been the synergistic effect of combining scientists with independent but overlapping research agendas and funding sources, and directing them toward a common goal. As the lead agency in this effort, the SWRC worked closely with local scientists and resource managers from the ARS Soil and Water Conservation Laboratory, University of Arizona (School of Renewable Natural Resources, and the Department of Hydrology and Water Resources), US Geological Survey, US Bureau of Land Management, Arizona Department of Water Resources, Cochise County Flood Control District, and US Army-Fort Huachuca. Additional ***SALSA*** participants included scientists from the ARS Remote Sensing Unit, US Environmental Protection Agency, Los Alamos National Laboratory, Jet Propulsion Laboratory, Utah State University, University of Iowa, ORSTOM (French scientific and development agency), IMADES (Mexican environmental agency), among others.

2. **Planning, Coordination, and Support**. These activities were crucial to the implementation of the ***SALSA** 1997 Riparian Campaign* on the USA portion of the watershed. The SWRC held numerous planning meetings with local scientists, hosted a large conference of ***SALSA*** participants in Tucson, and co-hosted an international conference in Hermosillo, Mexico. The SWRC coordinated research activities at the study site, and staff from the SWRC Tucson and Tombstone facilities provided logistical and material support to participating researchers, including site preparation, instrument installation, and data collection assistance.

3. **Data Collection and Analysis**. Scientists participating in the *1997 Riparian Campaign* collected abundant hydrological, biophysical, and meteorological data in FY 97; either continuously with electronic sensors and dataloggers, or at regular intervals during each 48-hour intensive measurement period ("synoptic run"). Four synoptic runs, representative of seasonal stress periods ("Pre-Greenup,", "Greenup," "Pre-Monsoon," and "Monsoon,"), were successfully completed. A fifth synoptic run ("Post-Monsoon") is scheduled for October 1997. Synoptic runs were centered around Landsat satellite overpasses, and included concurrent overflights by up to three remote sensing aircraft. As many as 60 scientists and technicians were fielded during a synoptic run, measuring factors as diverse as stream discharge using traditional hydrometric methods to atmospheric moisture using advanced laser technology. French and Mexican scientists, in addition to conducting their own land-surface experiments to the south, participated in the Monsoon riparian synoptic run. ***SALSA*** scientists are currently organizing and analyzing their respective data sets, exchanging information and preparing results for publication.

4. **Data Management and Dissemination**. Although the primary focus for FY 97 was data collection, efforts have been undertaken to prepare a comprehensive database that can serve ***SALSA*** scientists and the greater global change community. Experimental variable formats, database systems, and Internet access requirements have been discussed but not yet formalized. It is expected that the system will evolve as scientists organize and become familiar with the data sets collected this season. Scientists at SWRC have already acquired, or in the process of acquiring, a large number of remotely sensed images of the study area. US EPA cooperators have also been collecting and processing GIS and satellite imagery for the entire San Pedro River watershed. These spatial data sets will be combined with site-specific data to help extrapolate hydro-ecological conditions and processes in both time and space. ***SALSA*** scientists are actively preparing over 30 research papers for publication in the proceedings of the January 1998 meeting of the American Meteorological Society. Authors will present their papers at special oral and poster sessions convened to address ***SALSA*** and related research.

Future Plans: 1998 Field activities will concentrate on the uplands research in Mexico and addressing gaps in the 1997 campaigns. Reduction and journal publications of the 1997 results will also be a major near-term focus. Planning for research and field experimentation in the other highly uncertain basin processes of mountain front and ephemeral recharge will also be conducted.

Publications

Goodrich, D.C., Maddock, T., MacNish, R., Moran, M.S., Shuttleworth, J., and Williams, D.G. Measurements of GW, SW, and ET fluxes in a semi-arid riparian system as part of the SALSA program. *EOS*, Transactions, American Geophysical Union 1996 Fall Meeting, Vol. 77, No. 46, Nov. 12, 1996/Supplement, p. F260, 1996.

Vionnet, L.B., Maddock, T., Goodrich, D.C. Investigation of stream-aquifer interactions using a coupled surface-water and ground-water flow model. *EOS*, Transactions, American Geophysical Union 1996 Fall Meeting, Vol. 77, No. 46, Nov. 12, 1996/Supplement, p. F248, 1996.

Kepner, W.G., Riitters, K.H., Watts, C., Edmonds, C.M., Goodrich, D.C., A landscape approach to monitoring and assessing ecological condition in an international watershed, San Pedro river case study. 8th U.S./Mexico Border States Conference on Recreation, Parks, and Wildlife. Feb. 26-March 1, 1997, Hermissillo, Mexico. (Poster Presentation)

CARBON DIOXIDE AND MOISTURE FLUXES ON NORTH AMERICAN GRASSLANDS

Principle Scientists: William E. Emmerich

Cooperating Scientists: Ray Angell, Jim Bradford, Bill Dugas, Al Frank, Marshall Haferkamp, Kris Havstad, Jack Morgan, Nick Saliendra, Jerry Schuman, Phillip Sims, and Tony Svejcar.

ARS GCRP: Res. Areas: I; Prog. Elements: B; Objs: 1; Tasks: 2.

CRIS Numbers: 5342-13610-005-00D

Problem: The annual increase in atmospheric CO_2 is less than half released by anthropogenic sources. Rangelands have been suggested as a sink for the CO_2 because of their large geographical extent, but there is no effort to assess CO_2 fluxes across the range of environmental biomes where rangelands exists.

Approach: ARS scientists at twelve locations are cooperating in making carbon dioxide and moisture flux measurements across western regions of the U.S. with widely contrasting rangeland vegetation and species composition. At each location, carbon and moisture dynamics will be measured on grasslands typical of the area and on areas of particular interest, for example different management, grazing, or burning practices that could influence the fluxes.

Findings: Campbell Scientific Bowen Ratio systems that measure carbon dioxide and moisture fluxes were installed in June 1996 on a native grassland and brush dominated sites to compare strongly contrasting vegetation types. Carbon dioxide uptake increased during the summer growing season along with evapotranspiration (Figure 1). During the nongrowing season there was very low flux of carbon dioxide toward the soil surface (Figure 2).

A chapter for Special Report on the Regional Impacts of Climate Change of the Intergovernmental Panel on Climate Change (IPCC) was written.

Future Plans: Make flux measurements for a least two years and determine carbon pools in soil and biomass. Carbon budgets will be calculated with soil, biomass, and flux measurements to determine if the two plant communities are overall sources or sinks of carbon to the atmosphere. Water balance budgets will also be evaluated with precipitation, surface runoff, and evapotranspiration measurements.

Publications: Denis D'Amours, Mark Weltz et al. Contributors: Richard Adams, Dave Goodrich, Mary Kidwell et al. Chapter 8. North America. *In*. Special Report on the Regional Impacts of Climate Change of the Intergovernmental Panel on Climate Change. (in press)

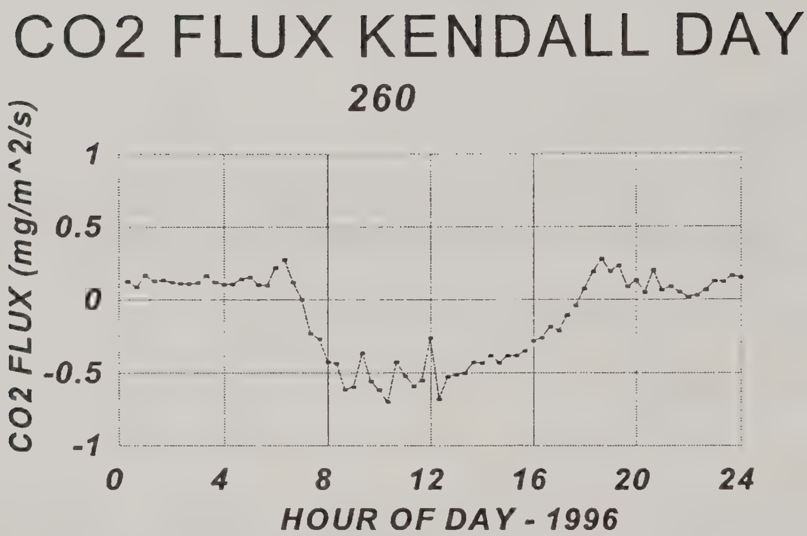


Figure 2 Typical carbon dioxide flux for the native grassland site (Kendall) during the growing season. Negative values indicate flux toward soil surface.

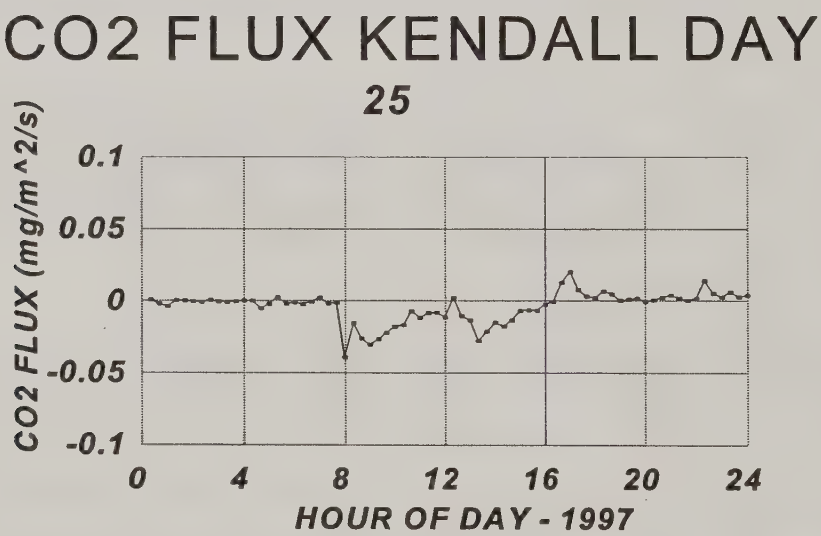


Figure 3 Typical carbon dioxide flux for the native grassland site (Kendall) during the nongrowing season. Negative values indicate flux towards the soil surface. Note differences in scale to Figure 1 and very little positive flux during the night.

EVALUATING ENSO AND OTHER LARGE-SCALE FORCING EFFECTS ON PRECIPITATION

Principal Scientist: Dr. David Goodrich, Tim Keefer

Cooperating Scientists: Dr. Donald Davis, Dr. Greg Johnson, Dr. David Woolhiser

ARS GCRP: Res. Area 1; Prog. Ele. A; Objectives 4,5; Tasks 4.4, 5.1-2

CRIS Numbers: 5342-13610-005-00D

Problem: Current daily precipitation models underestimate the variances of observed monthly, seasonal and annual precipitation occurrence and amount. Effects of non-periodic large-scale atmospheric forcings (e.g. ENSO) have been shown to be detectable in daily precipitation signals and may be significant factors in seasonal and interannual variability. Whereas individual raingages have been used previously, dense raingage networks may enhance the detection of connections between remote forcings and localized precipitation with respect to elevation, region, and season.

Approach: Seasonally-varying daily-precipitation model parameters under influence of atmospheric forcings are optimized using maximum likelihood techniques. SOI perturbations to model parameters are evaluated for significant effects for southwest U.S. and northern Mexico stations. Sequences of modeled daily precipitation with and without SOI perturbations are evaluated using statistical hypothesis testing and an objective criterion. SOI and PNA are being investigated for influence in Arizona and Idaho, areas with opposite precipitatioin response during El Nino episodes.

Findings: SOI perturbations have statistically significant impacts on daily-precipitation model parameters which result in statistically significant improvements in modeled daily precipitation. SOI effects during winter (November through April) are to increase modeled daily precipitation occurrence and amount, and increase the variance of monthly precipitation totals over simulated precipitation without SOI perturbations for one Arizona and two Sonora, Mexico stations. The Nash-Sutcliffe efficiency statistic is increased when SOI perturbed model results are compared to observed precipitation at the Arizona station, indicating model improvement.

Future Plans: Evaluate the differences between SOI perturbed model parameters optimized for an individual raingage and those of a dense raingage network, at watershed and basin scales, incorporating elevation and season attributes, for distinct U.S. regions. Incorporate algorithms for SOI effects into weather generators. Exploit the apparent lead-time between SOI and local precipitation for improved conditional simulations.

Publications: Keefer, T.O. and D.C. Goodrich. 1997. Southern Oscillation monthly effects on daily precipitation modeling. Submitted to Water Resources Research , in revision.

Presentations: Keefer, T.O. and D.C. Goodrich. Southern Oscillation monthly effects on daily precipitation modeling. AGU-Hydrology Days, Fort Collins CO, April, 1997.

Global Change Progress Report, 1997
Mark S. Seyfried

Objective 1. Analyze and interpret scale effects of hydrologic and atmospheric processes, taking into account spatial and temporal variability.

Task 2. Test the temporal stability hypothesis for soil water.
Cooperating Scientists: Kala Pandit, University of Idaho graduate student.

There were two purposes for this study, one was to examine spatial correlation scales for soil water content, the other was to determine if individual sampling sites exhibited temporal stability in terms their relative ranking among other sites. This could potentially enable the description of relatively large areas using a few point measurements. Soil-water content data have been collected on two different watersheds on five different dates. We have completed geostatistical analysis of soil-water content variability. These have yet to be analyzed in terms of temporal variability and we will do some additional trend analysis to establish if there is nonstationarity in the data. Current indications are that temporal stability is associated with easily observable spatial variability.

Task 3. Quantify runoff generation and identify dominant hydrologic processes over a range of scales.
Cooperating scientists: Brad Wilcox Scientific Officer, IAI, SP, Brazil;
Kala Pandit, University of Idaho graduate student
Gerald Flerchinger, UDSA-ARS, Boise, ID.

We are currently collecting soil-water content data using TDR at different sites in Reynolds Creek. Previous work has indicated that there should be a relationship between the "greeness", as measured by vegetation indices (we are using SAVI), and the soil water regime. This could provide valuable information in terms of how to partition or divide soil within the region because we want to separate only those soils that exhibit substantial variations in soil water regime. We have also found that there is a strong temporal component to spatial variability of soil water in the region. During the dry summer months the spatial variability is minimized, permitting fairly precise portrayal of soil water content over large areas.

Papers I have submitted or published under this particular objective (excluding abstracts and other ARS reports) are:

"Spatial Variability Constraints to Modeling Soil-Water at Different Scales" by M.S. Seyfried, submitted to Geoderma.

Seyfried, M.S., and G.N. Flerchinger, and M.D. Murdock. 1997. Spatial variability of frozen soil runoff at different scales. International Symposium on Physics, chemistry and ecology of seasonally frozen soils, p. 219-226.

Seyfried, M.S., and G.N. Flerchinger. 1996. Effects of scale on frozen soil runoff. **In** Scale Problems in Hydrology Fourth International Workshop p. 28. Vienna, Austria.
Seyfried, M.S., and B.P. Wilcox. 1995. Scale and the nature of spatial variability: field examples and implications for hydrologic modeling. Water Resour. Res. 31:173-184.
Seyfried, M.S. Nature and amount of spatial variability of soil water at multiple scales. 1995. **In** Silva, D. (Ed). Vadose Zone Hydrology: cutting across disciplines. pp 127-128. Davis CA Sept. 6-8.
Seyfried, M.S. Field calibration and monitoring of soil-water content with fiberglass electrical resistance sensors. 1993. Soil Sci. Soc. Am. J. 57:1432-1436.

Global Change Progress Report, 1997
Mark S. Seyfried

Objective 2. Utilize new technologies for parameter estimation and system evaluation of hydrologic and atmospheric models.

Task 1. Incorporate new technologies (geographic information systems, remote sensing, etc.) Into a new generation of hydrologic models.

We are currently modifying the ERHYM (Ekalaka Rangeland Hydrology and Yield Model) developed on a point scale by the ARS (largely Wight and coworkers). Modifications to the current version of ERHYM include a redistribution algorithm, an altered soil evaporation algorithm, and extensive evapotranspiration model testing. This model is linked to a GIS and will be partly parameterized using remote sensing. These changes will make it possible to apply the model to large heterogeneous landscapes characteristic of western rangelands.

Task 2. Collect, process and analyze remotely sensed and conventional water and energy flux data in basin scale field experiments.

Cooperating Scientists: P. Clark, USDA-ARS, Boise, ID
P.E. O'Niell, NASA, Goddard
J. Ritchie, USDA-ARS, Beltsville, MD
S. Goyal, Idaho Dept. Water Reources, Boise, ID.
C. Neale, Utah State University, Logan UT
G. Anderson, USDA-ARS, Welaco, TX

We are just finishing up the second and probably last field season collecting leaf area index, soil water content and Bowen ratio measurements at representative sites with the Reynolds Creek watershed. Videography has been obtained in cooperation with Utah State University to provide a link between satellite imagery and ground measurement of LAI. These will be related to different plant communities. We are currently evaluating the use of satellite imagery for classifying critical plant communities in the region. In addition, different LAI measurement techniques for rangeland, particularly those dominated by shrubs, are being evaluated.

Papers published or submitted under this objective (excluding abstracts and other ARS reports) are:

"The Effect of DEM Resolution on Topographic Correction of Synthetic Aperture Radar Imagery", by S.K. Goyal, M.S. Seyfried and P.E. O'Niell, submitted to the International Journal of Remote Sensing.

Ritchie, J.C., and Seyfried, M. S. 1997. Airborne laser altimeter applications to water management. Remote Sensing and Geographic Systems for Design and Operation of water Resources Systems. IAHS Pub. No. 242.

Shi, J., P. O'Neill, A. Hsu, J.J. van Zyl and M.S. Seyfried. 1994. Estimation of soil moisture and surface roughness parameters using L-band SAR measurements. Conference on Microwave Sensing for Forestry and Hydrology 2314: 1-9.

O'Neill, P.E., A.Y. Hsu, and M.S. Seyfried. 1994. SAR terrain correction for improved soil moisture estimation in a mountain watershed. Annual IGARSS meetings, 8-12 Aug.,1994.

O'Neill, P.E., T.J. Jackson, N.S. Chauhan, and M.S. Seyfried. 1993. Microwave soil moisture estimation in humid and semiarid watersheds. Advances in Space Res. 13:115-118.

USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi
Channel and Watershed Processes Research Unit (CRIS No. 6408-13000-007)
Web Site: www.sedlab.olemiss.edu/cwpN.html
Contact: Carlos V. Alonso, Email: alonso@sedlab.olemiss.edu

NSL PARTICIPATION IN PROJECTS RELEVANT TO THE NATIONAL GLOBAL CHANGE PROGRAM

The SURFRAD Network: SURFRAD, a network of high quality surface radiation budget stations has been stablished by NOAA's Air Resources Laboratory for long-term monitoring and climate research, and to supply comprehensive surface radiation budget data for climatic regions ranging from cold and dry to warm and moist. These stations were installed between April 1994 and July 1995 at the USDA Goodwin Creek Experimental Watershed in Mississippi; Fort Peck, Montana; Bondville, Illinois; and Table Mountain near Boulder, Colorado. Independent measures of upwelling and downwelling, solar and infrared are the primary measurements at each station, and include direct and diffuse solar, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters. The SURFRAD stations are part of the Baseline Surface Radiation Network that provides ground-based radiative flux measurements for the Surface Radiation Budget project and for validation of other satellite-based measurements of radiative fluxes established in support of the international Global Energy and Water Cycle Experiment (GEWEX). SURFRAD data are valuable for validating hydrologic, weather, and climate prediction models, and to detect trends in the earth's climate.

The Mississippi Basin Carbon Project: The U.S. Geological Survey and the National Sedimentation Laboratory are cooperating in the Goodwin Creek Experimental Watershed to further the understanding of the interactive effects of land-use, erosion, sedimentation, and soil development on carbon storage and nutrient cycles in support of the USGS Mississippi Basin Carbon Project (MBCP). This collaborative effort is part of the national USGS Global Change Research Program. The project is motivated by the need to increase our knowledge of the role of terrestrial carbon in the global carbon cycle, particularly in the temperate latitudes of North America between 30° and 60° N. This land area is thought to be a large sink for atmospheric CO_2, but the identity of this sink is unknown. By examining a variety of spatial scales, including the whole Mississippi Basin, it is anticipated that those aspects of environmental change that have particularly large effects on carbon, nutrient, and sediment cycles can be identified. Because of the scale of the effort interagency collaboration is essential and currently involves the COE, the Large Lakes Observatory, LSU, NOAA, NRCS, NSL, the UM Limnological Research Center, and USGS.

The NEXRAD Project: Rainfall intensity and rainfall kinetic energy are both quantities needed to quantify aspects of precipitation relevant to many hydrological applications and, in particular, accurate estimates of soil erosion by rainfall. NSL is collaborating in a research project led by scientists from Princeton University and the University of Washington, and aimed

at using radar data to provide rainfall rate and rainfall kinetic energy concurrently, while covering very large areas with high spatial and temporal resolution. This study uses data collected in the Goodwin Creek Experimental Watershed which is under radar coverage from the NEXRAD WSR-88D radar station in Memphis, TN. Current practices usually depend on sparse raingauge networks that do not represent accurately the area covered by a storm, and do not describe the high spatial variability observed in precipitation events. Another severe limitation is that they do not provide accurate information about heavy convective storms associated with substantial soil removal due to large vertical downdrafts and significant wind speeds that cannot be captured by a raingauge network. With the installation of the Next Generation Weather Radar (NEXRAD) network of WSR-88D (Weather Surveillance Radar - 1988 Doppler) covering the United States, the opportunity now exists for accurate estimation of the rainfall kinetic energy flux using radar reflectivity.

The GCIP LSA-East Project: The Global Energy and Water Cycle Experiment (GEWEX) has established Continental Scale Experiments to improve scientific understanding and to model on a continental scale the coupling between the atmosphere and the land surface hydrologic processes for climate and water resources prediction purposes. The GEWEX Continental-scale International Project (GCIP) was established in the Mississippi River basin in 1992 to take advantage of the extensive meteorological and hydrological networks operated by a wide range of federal and state organizations. GCIP research and data collection activities occur in a phased timetable and emphasize a particular region with special characteristics for a period of about two years. Four Large Scale Areas (LSAs) have been identified which encompass major river sub-basins of the Mississippi River basin. NOAA and NASA plan the next LSA-East phase activities, with focus on the Ohio River basin including the Tennessee and Cumberland River basins, during 1988-1999. The NSL Goodwin Creek Experimental Watershed was selected to participate in this effort because of its extensive hydrologic instrumentation, current involvement in the SURFRAD Project, collaboration on the NEXRAD research program, and proximity to NOAA's Wind Profiler installation at Okolona south of Tupelo, Mississippi.

The TOPAZ+SWAT+DWAVNET, and AnnAGNPS Modeling Projects: Modeling tools are needed to allow predictions of potential global change effects on watershed management, streamflow response, crop production, and wildlife habitat. Geographic information systems and a digital terrain analysis tool (TOPAZ) have been successfully integrated with the SWAT model to predict long-term runoff, sediment yield, and interactions of hydrologic processes in large river basins. Most upland channels in the Mississippi River basin experience ephemeral flows, are heavily destabilized by headcut migration, and a variety of bio-structural measures are used for grade control and stream bank stabilization. The stream flow routing model DWAVNET developed by NSL was coupled with SWAT to account for these channel evolution and control features. The TOPAZ+SWAT+DWAVNET scheme was used successfully to simulate runoff and sediment yield data from the NSL Goodwin Creek Experimental Watershed for the 10 year period 1982-1991. NSL has also assumed leadership for the development of AnnAGNPS. This is a continuous-simulation, surface-runoff, pollutant loading computer model that integrates the processes that occur from upland areas as they pass through the watershed and determine how management decisions impact the water quality and ecology of the system.

Field-Scale Hydrometeorology During Spring Snowmelt: Model Evaluation and Improvement Through Comprehensive Measurement.

J.M. Baker
USDA-ARS Soil & Water Management Unit
St. Paul, MN 55108

Cooperating Scientists: K.J, Davis, J.C. Bell, University of Minnesota

Problem:

Late winter/early spring is a critical time of the hydrologic year in the Upper Midwest. Typically, nearly all of the precipitation that has fallen over the winter is still present in a snow and ice pack on the surface. As sun angle and daylength increase this pack begins melting, but infiltration is inhibited by the diminished permeability of the frozen soil below. The disposition of this meltwater is of critical importance for flood prediction and for recharge of soil moisture depleted during the previous growing season. The disposition of available energy during this period is important for weather and general circulation models. Unfortunately, a clear understanding of the constituent processes has been elusive. In large measure this is due to a scarcity of complete, comprehensive field data sets that include a) the meteorological forcing inputs; b) soil state variables; c) relevant soil properties ; and d) resultant fluxes. The variables controlling surface energy and water partitioning are difficult to measure during a time of year when water is changing phase within the soil and snowpack, often on a diurnal basis. Soil moisture and infiltration measurements under these conditions are difficult to make, and hence quite rare. The same is true of latent and sensible heat flux measurements. Data sets that contain both and also include the relevant meteorological measurements are effectively nonexistent.

Models that might be relevant differ considerably in scale, in the processes included, and in the level of empiricism with which those processes are treated. Decisions must be made regarding the necessary level of complexity (or acceptable level of simplicity) and the appropriateness of linking various limited component models into more comprehensive systems that might provide the desired predictive capabilities. This can best be done via direct evaluation using reliable field data of the sort described above. A scheme for such comparisons has been developed for the NOAA PILPS program, and their list of necessary measurements is an appropriate starting point.

Approach:

There are three University of Minnesota Agricultural Experiment Stations in the southern portion of the state where portions of the necessary data are already being collected. At the Rosemount station, 20 km south of St. Paul, nearly all requisite variables are already being measured at a long-term USDA-ARS research site. Data collected include soil water content and temperature profiles, all components of the radiation balance, temperature, humidity, wind profile, liquid-equivalent precipitation, and snow depth. In addition, considerable research has been conducted at the site concerning automated, multiplexed measurement of soil water content, liquid water content in frozen soil, and the infiltration of snowmelt. Finally, a conditional sampling system has been developed at the site that permits year-round measurement of CO_2, latent, and sensible

heat fluxes. Minor additions are being made to provide all information from this site for PILPS-style model evaluations. The Waseca Experiment Station is located 100 km south of St. Paul, within the Le Sieur river basin, a tributary of the Minnesota River. There is a weather station on site, and there is an ongoing project in which soil moisture is monitored at different landscape positions. The Lamberton Experiment Station is located 175 km southwest of St. Paul, in the basin of the Cottonwood River, another tributary of the Minnesota River. Again there is a weather station on site, and the Lamberton station has a long-term soil moisture project, in which profile water contents have been measured weekly from spring thaw to fall freeze for more than twenty years. Instrumentation is being added at these sites to provide all components of the radiation balance, winter precipitation measurements, and soil moisture and temperature profiles.

Findings:

Data from previous winter seasons at Rosemount are already being used to test frozen soil algorithms that have been added to the ETA model, which is a principal forecasting model used by the National Weather Service. These data have also been used to test components of the SHAW model, specifically its algorithms for radiation balance and sensible heat flux during snowmelt. The model performed well in predicting the timing of final snowmelt, but overestimated sensible heat flux somewhat during the snowmelt period, which may be due to the difficulty of parametering aerodynamic resistance during stable periods. Overall the model performed well.

Future Plans:

Additional soil moisture and temperature data across the landscape are necessary to resolve some of the questions regarding routing of snowmelt in the Upper Midwest, and we hope to address that in 1998. A second question that will be addressed through a related, but separately funded proposal will be boundary layer development over partially snow-covered surfaces.

Relevant Publications:

Flerchinger, G.N., J.M. Baker, and E.J.A. Spaans. 1996. Simulating the radiative energy balance over snow cover using the SHAW model. Hydrologic Processes. 10:1359-1367.

Bland, W.L., P.A. Helmke, and J.M. Baker. 1997. High-resolution snow-water equivalent measurement by gamma-ray spectroscopy. Agric. Forest Meteorol. 83:27-36.

Baker, J.M., and E.J.A.Spaans. 1997. Mechanisms of meltwater movement above and within frozen soil. Pp. 31-36 in Proc. Intl. Symp. on Physics, Chemistry, and Ecology of Seasonally Frozen Soils, I.K. Iskandar, E.A. Wright, J.K. Radke, B.S. Sharratt, P.H. Groenevelt, and L.D. Hinzman (eds). Spec. Rept. 97-10, U.S. Army Cold Regions Research andEngineering laboratory, Hanover, NH.

Baker, J.M., G.N. Flerchinger, and E.J.A. Spaans. 1997. Sensible heat exchange during snowmelt. In “Models for Cold-regions Contaminant Hydrology”, S.A. Grant (ed). Ann Arbor Press, Ann Arbor, MI.

Development and Validation of an Interactive Climate-Vegetation-Soil Model to Predict Potential Climate Change Effects on Early Plant Establishment

Principal Scientist: S.P. Hardegree
Cooperating Scientists: Gerald Flerchinger, Clayton Hanson
CRIS Numbers: 12610; 13610

ARSGCRP: **Program Element II, Objective 2** - Interactively utilize natural resource models as a basis for developing mitigation and adaptive strategies to avoid or minimize the negative effects, and optimize the positive effects of global change on managed ecosystems within the global environment.

Stuart Hardegree, Gerald Flerchinger, Clayton Hanson
Northwest Watershed Research Center, Boise, Idaho, September 20, 1997

Problem:

Climate change is expected to have a large impact on water resources through its effect on the hydrologic cycle. Rapid change may limit natural species migration, adversely affect plant productivity and native plant diversity, and result in a redistribution of wildland plant species and plant community types. New technology must be developed: to assess potential climate change effects on the distribution of wildland plant species; and to restore and maintain native plant diversity under current and future climatic scenarios.

Approach:

Critical factors determining successful establishment of wildland plants are the spatial and temporal distribution of soil heat and moisture relative to growth response of both desirable plant species and weedy competitors. The general approach taken in this program is to assess historical, current and potential future weather impacts on seedbed temperature and moisture as they relate to establishment of desirable and weedy plant species.

Findings:

Soil temperature data from the Orchard Field Test Site in southern Ada County, Idaho, have been used to program laboratory germinators to simulate field-variable thermal regimes. Hydrothermal germination response models have been developed to assess potential germination response of native grass species and introduced annual weeds to variable conditions of seedbed temperature and moisture. Thermal response models for 19 accessions of 5 native perennial species (bluebunch wheatgrass, Pseudoroegneria spicata; thickspike wheatgrass, Elymus lanceolatus; sandberg bluegrass, Poa sandbergii; bottlebrush squirreltail, Sitanion hystrix; and basin wildrye, Leymus cinereus) have been shown to accurately predict cumulative germination response under field-variable temperature regimes to an accuracy of ± 0.5 days. The Boise laboratory is currently screening germplasm from the ARS Forage and Range Research Laboratory in Logan Utah. The FRRL has collected native grass seeds from all over the western U.S. and planted them in a nursery environment to reduce environmental effects on seed production. NWRC is planning on screening 54

accessions of Sitanion hystrix for hydrothermal germination response in the coming year. This will make it possible to test species-level inferences about establishment response of this important range grass species to current and potential-future seedbed microclimatic regimes. Field emergence of these grasses has been monitored for the last 5 years at the Orchard Field Test Site. The Orchard site is instrumented with a full weather station and soil water and temperature sensors from near-surface to 1m depth. These data are currently being used for calibrating the SHAW model for predicting historical and potential future-variability in seedbed microclimate.

Recent Publications:

Emmerich, W.E. and S.P. Hardegree. 1996. Partial and full dehydration impact on germination of four warm-season grasses. Journal of Range Management 49:355-360.

Hardegree, S.P. 1996. Optimization of seed hydration treatments for enhancement of low-temperature germination rate. Journal of Range Management 49:87-92.

Hardegree, S.P., F.B. Pierson, G.L. Johnson, G.N. Flerchinger and C.L. Hanson. 1996. Seedbed microclimatic modeling for burn rehabilitation planning in the Great Basin region of the western United States. In: Proceedings of the Fifth International Rangeland Congress. Volume I. Neil West (ed.). Salt Lake City, UT, July 23-28, 1995. pp. 207-208.

Hardegree, S.P., F.B. Pierson, G.L. Johnson, G.N. Flerchinger, C.L. Hanson, and J.R. Wight. 1996. Effects of climate change on early plant establishment. Maintenance and restoration of native plant communities in the Great Basin. In: Global Change and Agriculture: Soil, Water, and Plant Resources, Volume III: Papers and Presentations. USDA-ARS-Global Change Research Program. pp. 34-42.

Johnson, G.L., C.L. Hanson, S.P. Hardegree and E.B. Ballard. 1996. Stochastic weather simulation: Overview and analysis of two commonly used models. Journal of Applied Meteorology 35:1878-1896.

Pierson, F.B., S.P. Hardegree, G.N. Flerchinger and J.R. Wight. 1996. Spatial and temporal variability of seedbed microclimate on rangelands: characterization and modeling. In: Proceedings of the Fifth International Rangeland Congress. Volume I. Neil West (ed.). Salt Lake City, UT, July 23-28, 1995. pp. 446-447.

LINKAGE OF TOPOGRAPHIC ANALYSIS SOFTWARE TO HYDROLOGIC MODELS

Principle Scientist: J. Garbrecht
Cooperating Scientists: L. Martz, G. Kite, R. Bingner, J. Nelson, M Lacroix
ARS GCRP: I.A.2.1., II.B.1.
CRIS Number: 6218-13610-009-00D

Problem: Existing software for processing of Digital Landscapes (DEM) is usually imbedded in a Geographic Information System (GIS). Using such DEM software to incorporate into or modify for hydrologic and environmental model applications is often expensive (cost of GIS), cumbersome (different standards and languages), or unpractical (difficult to program into GIS).

Approach: Provide a stand alone software (TOPAZ) in standard FORTRAN that solves the numerical algorithms for DEM processing and provides intermediate and final raster and tabular data in a format that can be used directly by models, for further data manipulation, or for importation into a GIS.

Findings: The TOPAZ software has been used as a stand alone package for the preparation of the Agricultural Non-Point Source (AGNPS) model drainage network; portions of TOPAZ have been used for topographic data preparation in the commercial Watershed Management System (WMS) by Brigham Young University; TOPAZ has been used for watershed data preparation in the distributed conceptual hydrologic SLURP model (Canada).

Future Plans: Implementation of the software in FORTRAN90 to take advantage of the dynamic memory allocation and to facilitate the interface to other software languages.

Publications:

Bingner, R. L., R. W. Darden, F. D. Theurer, and J. Garbrecht. 1997. GIS-Based Generation of AGNPS Watershed Routing and Channel Parameters. American Society of Agricultural Engineers, Paper No. 97-2008, St. Joseph, Michigan , 4 p.

Bingner, R. L., J. Garbrecht, J. G. Arnold, and R. Srinivasan. Effect of Watershed Subdivision on Simulated Runoff and Fine Sediment Yield. Transactions of the American Society of Agricultural Engineers. In Press.

CLIMATOLOGIC DATA SET FOR THE LITTLE WASHITA RIVER WATERSHED

Principle Scientist: J. Garbrecht, P. J., Starks
Cooperating Scientist:
ARS GCRP: I.B.1.
CRIS Number: 6218-13610-009-00D

Problem: Continuous climatic measurements are made on the Little Washita River Watershed (LWRW), a 611 km**2 ARS research watershed. Maintaining, quality controlling and archiving the climate data is an essential step to a quality research data base. Measured precipitation has shown some systematic variation with air temperature which need correction.

Approach: The measured climatic variables are subjected to the new quality control procedures of the Oklahoma MESONET. The results of the quality control drive the maintenance and repair, and a quality control flag is provided with each measurement to quantify the reliability of the measurement. A regression analysis is conducted on the precipitation data versus air temperature to find a correction procedure for past data values.

Findings: The data is quality controlled and found to be of good quality for nearly all measurements. Repairs/calibrations are preformed when indicated by the quality control. A correction coefficient has been developed for the past precipitation data. New tipping bucket raingages gages have been installed to overcome the air temperature dependency of the old gages and to insure consistency with the Oklahoma MESONET climate data measurements.

Future Plans: The past raingage data will be back corrected to remove most of the air temperature dependency. The climate data from all station in the LWRW will be archive on a quarterly basis in ASCII format.

GEOGRAPHICAL INFORMATION SYSTEMS COVERAGES FOR THE LITTLE WASHITA RIVER WATERSHED

Principle Scientists: Patrick Starks, Jurgen Garbrecht
Cooperating Scientists: John Ross, Frank Schiebe
ARS GCRP: I.A.2.2
CRIS Number: 6218-13610-009-00D

Problem: Development of geographical information systems coverages for the Little Washita River Watershed (LWRW) in support of hydrologic, rangeland ecosystem, and climate change research.

Approach: These coverages are many and varied and include soils, digital elevation models, and landuse as the major categories. A digital elevation models (DEM) is used as input to derive coverages of standard watershed parameters such as watershed boundaries, stream networks, sub-watersheds, slope and aspect. TOPAZ is used to produce these DEM-derived coverages. The DEM (30 X 30 m horizontal, 1 foot vertical resolution) for the LWRW was produced by the United States Geological Survey. Spring, summer, and fall LANDSAT satellite scenes are used to produce historical landuse patterns for every even-numbered year from 1972 to 1994. All scenes are geometrically corrected, radiometrically calibrated and reduced to exoatmospheric reflectance. Unsupervised classification schemes are used to produce seasonal landuse patterns. A soils coverage is developed from STATSGO data base. The basic 30 X 30 m soils coverage is composed of digitized soil mapping units. A soil attribute file is linked to the soil mapping unit coverage through soil code identifiers, whereby a number of soil coverages may be derived.

Findings: The soils and basic DEM coverages are complete.

Future Plans: Additional landuse classification work is in progress.

Publications:

Berry, C. 1995, Multitemporal land cover classification of the Little Washita Watershed using the Kauth-Thomas greenness vegetation index. Unpublished MS thesis, Oklahoma State University, Stillwater, OK.

Starks, P.J., J. Garbrecht, and F.R. Schiebe, 1996, Establishment of missions of the Little Washita River research watershed. In: H.J. Morel-Seytoux (ed.) *Proceedings of the 16th Annual American Geophysical Union Hydrology Days*, April 15-18, Colorado State University, Fort Collins, Colorado, pp. 479-486.

Starks, P.J., J.D. Garbrecht, F.R. Schiebe, J.M. Salisbury, and D.A. Waits, 1996, The development and use of GIS coverages for the Little Washita River watershed. In: Hallam et al. (eds.), *Proceedings of the AWRA Annual Symposium, GIS and Water Resources.* American Water Resources Association, Herndon, Virginia, TPS-96-3, pp. 56.

USE OF REMOTELY SENSED DATA TO ESTIMATE PLANT BIOPHYSICAL PROPERTIES

Principle Scientists:	Patrick Starks, Robert Williams
Cooperating Scientists:	Frank Schiebe, Karen Humes
ARS GCRP:	I.A.2.2
CRIS Numbers:	6218-13610-009-00D

Problem: Large-scale hydrologic models require extensive data sets for parameterization and output validation. Traditional point measurements are uneconomical to obtain and apply at large scales. Remoely sensed data offers an economical, timely and large area view of the landscape and needs to be evaluated for its usefulness in quatifying vegetative characteristics (biophysical properties) which affect the partitioning of the energy and hydrologic balances.

Approach: Acquire thermal remotley sensed data over the Little Washita River watershed to estimate temperatures from four typical surfaces found in the study area. Use optical remotely sensed data to estimate leaf area index for these same surfaces.

Findings: Leaf area indexes were estimated using multi-band, optical remotley sensed data in conjunction with neural networks.

Future Plans: Continue to work with thermal remotely sensed data to estimate surface temperatures and correcting for atmospheric effects. Evaluate temporal and spatial variability of the watershed in terms of thermal signatures and continue investigations into determination of leaf area index, biomass, forage quality using remotely sensed data.

Publications:

Starks, P.J., R.D. Williams, and M.A. Owens, 1996. Estimating leaf area index using remotley sensed data and neural networks, *Agronomy Abstracts*, American Society of Agronomy Annual Meeting, Indianapolois, Indiana, Nov. 3-8, p. 18.

SIMULATING EVAPOTRANSPIRATION AND SURFACE ENERGY FLUXES ON SEMI-ARID RANGELANDS

Principle Scientist: G.N. Flerchinger,

Cooperating Scientists: C.L. Hanson, S.P. Hardegree, W.P Kustas, and M.A. Weltz

ARS GCRP: Research Area WR; Program Element I; Objective 1; Task 4
Research Area WR; Program Element I; Objective 3; Task 1

CRIS Numbers: 5362-13610

Problem:
Variability of energy and water fluxes across a landscape due to changes in soils and vegetation complicate efforts to quantify or predict energy and water exchange between the surface and the atmosphere. Current models do not adequately address the spatial variation across a landscape. Improved process-oriented models will enable better quantification of water and energy fluxes.

Approach:
The Simultaneous Heat and Water (SHAW) model was used in this study to simulate the surface energy balance and surface temperature of two vegetation communities using data collected during the Monsoon '90 multidisciplinary field experiment. The two vegetation communities included a sparse, relatively homogeneous, grass-dominated community and a shrub-dominated site with large bare interspace areas between shrubs. Model simulations were compared measured energy fluxes and canopy and soil surface temperatures.

Findings:
The model mimicked the diurnal variation in the surface energy balance at both sites, while canopy leaf temperatures were simulated somewhat better at the relatively homogeneous grass-dominated site. The variation in surface fluxes accounted for by the model (i.e. model efficiency) ranged and 59% for latent heat flux at the shrub-dominated site to 98% for net radiation at both sites. Model efficiency for predicting latent heat flux at the grass-dominated site was 65%. Canopy leaf temperatures for the shrub-dominated site were consistently overpredicted by 1.8°C compared to measured values. Simulated soil surface temperatures at both sites had a model efficiency of 94% and a mean bias error of less of than 0.9°C.

The ability of the model to simulate canopy and soil surface temperatures gives it the potential to be verified and periodically updated using remotely-sensed radiometric surface temperature and soil moisture when extrapolating model-derived fluxes to other areas. A methodology was proposed whereby model predictions can be used with a combination of remotely sensed radiometric surface temperature and surface soil moisture to estimate soil water content within the rooting depth. (See graph on following page.)

Future Plans:
The model will be applied and calibrated to detailed temperature and moisture measurements collected at the Orchard site monitored by the Northwest Watershed Research Center. Additionally, incorporation of the SHAW model into a distributed modeling framework will increase the utility of the model for application to landscape areas.

Publications:

Flerchinger, G.N., C.L. Hanson, W.P. Kustas and M.A. Weltz. 1996. Modeling Evapotranspiration on Semi-Arid Rangelands. On: compact disk, C.T. Bathala (ed.), North American Water and Environment Congress. June 22-28, 1996, Anaheim, CA. ASCE, New York, New York.

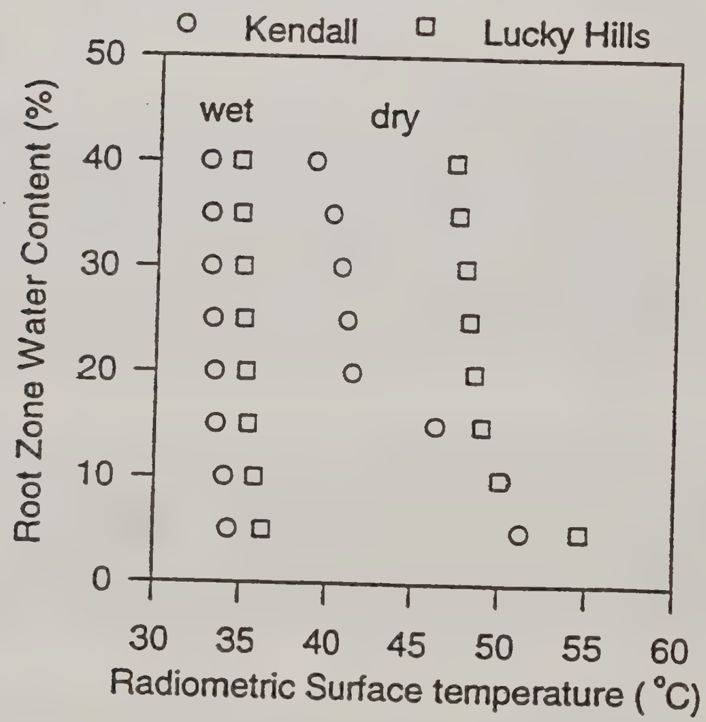
Flerchinger, G.N., C.L. Hanson and J.R. Wight. 1996. Modeling evapotranspiration and surface energy budgets across a watershed. Water Resour. Res. 32(8):2539-2548.

Flerchinger, G.N., J.M. Baker and E.J.A. Spaans. 1996. A test of the radiative energy balance of the SHAW model for snowcover. Hydrol. Proc. 10:1359-1367.

Flerchinger, G.N. and F.B. Pierson. 1997. Modeling plant canopy effects on variability of soil temperature and water: Model calibration and validation. J. Arid Environ. 35:641-653.

Flerchinger, G.N., K.R. Cooley, C.L. Hanson, and M.S. Seyfried. 1997. A uniform versus an aggregated water balance of a semi-arid watershed. Hydrol. Proc. (In press)

Flerchinger, G.N., W.P. Kustas and M.A. Weltz. 1997. Simulating Surface Energy Fluxes and Radiometric Surface Temperatures for Two Arid Vegetation Communities using the SHAW Model. J. Appl. Meteor. (Accepted)



Effect of soil water content within the root zone on simulated radiometric surface temperature for a selected day in mid-July during the Monsoon '90 study assuming two different surface soil moisture conditions.

SOIL WATER FLUX AND HEAT TRANSFER PROCESSES AT DIFFERENT SCALES

Principle Scientist:	Patrick Starks
Cooperating Scientists:	Jurgen Garbrecht, Robert Williams, Laj Ahuja
ARS GCRP:	I.A.1.4
CRIS Numbers:	6218-13610-009-00D

Problem: Soil water content represents a significant water storage volume in the land hydrologic cycle and affects the partitioning of incoming solar radiation into latent heat (evapotranspiration) and sensible heat (air temperature), and , thus, is important to both the energy and mass balance approaches in the quantification of the hydrologic cycle. The role of surface soil water content in this partitioning of solar radiation at a variety of scales and how spatial and temporal patterns of soil moisture are related to the physical and hydrologic properties of the soils is not well understood.

Approach: Measure the spatial and temporal variation of soil water and heat using 13 Soil Heat and Water Measurement Systems (SHAWMS) co-located with existing ARS Micronet meteorological stations on the Little Washita River watershed (LWRW). Ancillary soil characterization data (soil water retention curves, bulk density, infiltration, organic matter, soil texture and soil particle size distribution) will also be collected for each site.

Findings: All 13 SHAWMS have been installed and data have been collected for several months. We have experienced intermittent electrical problems and vandalism of the SHAWMS network, but the preliminary profile soil heat flux and temperature data look reasonable. Data from the in-situ soil moisture sensor calibration is undergoing analysis. Early indications are that more data points need to be collected before an adequate calibration can be established for each soil moisture sensor.

Future Plans: From in-lab calibration of similar soil moisture sensors, determine if a "universal" calibration equation can be applied to the LWRW instrumentation, and determine nature of error in soil moisture estimation if this equation is employed. Continue in-situ calibration. Begin analysis of spatial and temporal variability of soil water content and hat flux from the fully installed and operational SHAWMS network. Develop scaling theory for describing hydraulic properties of varying soil types for integrating water and energy fluxes at different scales. The Simultaneous Heat and Water model (SHAW) will be used to conduct short and long term heat, energy, and water budget analyses. The model will be validated and calibrated for bare soils and for a variety of grassland ground covers in Oklahoma. The SHWAMS field data and the SHAW model will be used to analyze and interpret the impact and implications of climate and spatial and temporal variability on agricultural soil moisture needs and forage production.

Publications:

Fisher, D.K., P.J. Starks, and R. Elliott. 1998. Progress in automated measurement of soil water in atmospheric and hydrologic networks in the Southern Great Plains. To be presented at the 10th Symposium on Meteorological Observations and Instrumentation, American Meteorological Society annual meeting, January 1998, Phoenix, Arizona. Abstract accepted and six-page proceedings preprint in progress.

Report for Global Change Project (Sept. 1997) Titled, "Incorporation of Storm-Generation and Large-Scale Atmospheric Influences In An ARS Stochastic Weather Model"

Progress

Much progress has been made on the project to investigate the use of Huff curves for stochastically simulating storm occurrence, depth, duration, and within-storm intensities, and supporting exploratory investigations. Many of the following tasks have been collaborative accomplishments between the Coshocton, Ft. Collins, Boise, Tifton, and Tucson locations:

- Significant progress on modifying the program to compute critical duration (CD), the minimum dry time that separates storms.
- Wrote programs and determined which data in the National Weather Service (NWS) nationwide data base should be used for developmental purposes (600+ stations with >20 yrs hourly data), and mapped both 15-min and 60-min stations nationwide.
- Found errors in NWS data and developed program to correct CD for poor data. Started developing data base for paper that will describe problems with using NWS data to compute CD. Randomly selected one NWS gage/state to show the extent of problem.
- Processed 30+ corrected NWS stations in CO, WY, NE, KS area to show how logarithm of CD can be spatially mapped. Paper to be written on this.
- Wrote a program to stochastically simulate storm occurrence, storm depth, storm duration, and within-storm intensities. The program accepts a variety of types of inputs for each component of procedure, including a variety of fitted frequency distributions and empirical distributions for each element. Procedure undergoing testing.
- Hired an associate to work on programming various aspects of the plan of work at Coshocton.
- Program written to read a variety of precipitation input including ARS, NWS, NAEW, Australian, and a standard input that was developed for the project. A standard set of precipitation codes was developed.
- The program was modified to select storms and identify the ones that have incomplete data in them.
- A program was written to compute monthly precipitation totals for use with CD analysis.
- Exploratory investigation into using PRISM estimates of monthly average precipitation for estimating CD in the CO, WY, NE, KS area.
- Much investigative work to find method to compare Huff curves for regionality and factors investigations. Initiating studies to use sliding polynomials and a 4-range discrete sample test for this purpose.
- Investigating the effect of using NWS fixed-time interval data on computing CD. Exploratory investigations into correcting CD estimates by comparing breakpoint and NWS data underway (effect of using hourly versus breakpoint data)
- Exploratory investigations into how CD varies with elevation using the Boise rain gage network

Other

- Bonta spent 4 months at the Great Plains Systems Research unit in Ft. Collins to further develop the stochastic precipitation model.
- Presented Huff curve concepts to the ARS National Program Staff and NRCS representatives in Beltsville (Bonta)
- Presented Huff curve concepts to the NWS (Bonta)
- Web page has been developed for the GEM weather-generator model by the NRCS and ARS with sections for various components of the present project (http://ars-boi/nwrc/climate/Gem.html).

- Manuscript: "Southern Oscillation Monthly Effects On Daily Precipitation Modeling" Keefer, T.O. and D.C. Goodrich, in revision.

  This paper identifies a linkage of the Southern Oscillation Index (SOI) to daily precipitation in the SW US and NW Mexico at intraseasonal time scales using a stochastic daily precipitation model (precipitation algorithm of USCLIMATE). Improvements to simulated daily precipitation are shown when SOI is included versus when SOI is not used (current status of USCLIMATE). These are indicated by comparison of simulated to observed precipitation and by improvement of second order statistics at monthly scales.
- Presentation of selected results of the above (1.) to NOAA - Univ. Arizona Southwest Assessment Meeting February, 1997 (Keefer.)
- Presentation of the above by at AGU-Hydrology days April, 1997 (Goodrich).

Future Research

- Write set of papers on the studies listed above.
- Continue with studies listed above.
- Continue testing of storm generator, starting first with storm occurrence, and then with within-storm intensities.
- In conjunction with NRCS (Greg Johnson), Boise ARS (C. Hanson), and Salt River Project (SRP), Phoenix (Jon Skindlov) we have planned to investigate and compare the influences of the SOI, sea surface temperatures (SST) and the Pacific North America Pattern (PNA) on regional precipitation in the southwest US using SRP and Walnut Gulch data and the northwest US using NWRC data from Reynolds Creek and nearby Idaho stations. This project will include elevation influences, the NW-SW opposition of hydrologic response during EL Nino episodes, and will be directed to application of intraseasonal modeling for water resource managers such as the SRP, NRCS, and World Agricultural Outlook Board (WAOB).
- Data from all stations have been supplied by each unit and initial parameterizations for Idaho stations have been completed.
- The regional approach will be expanded to include the continental US with special emphasis on the southern tier of states, an area with known substantial impacts from ENSO. Other continental US areas and teleconnections will be included. Data sources will initially be the USDA-ARS research watersheds dense raingage networks. With financial assistance from ARS GC Project a UA student will be hired to assist in collecting USDA-ARS watershed daily precipitation data sets, formatting input files of for model parameterizations, and proceeding with model simulations.

Estimating Climate Change Effects on Water Supplies
Using the Snowmelt Runoff Model (SRM)

Principal Scientist: Albert Rango

Cooperative Scientist: Jaroslav Martinec

ARS GCRP: Res. Areas: III; Prog. Elements: A; Objs.: 1; Tasks: 4.

CRIS Numbers: 1270-13610-004-00D

Problem: As a result of increasing atmospheric CO_2, significant global warming along with regional changes in precipitation and cloudiness are expected. Both increases in temperature and changes in precipitation input will affect the accumulation and ablation of mountain snowpacks, the major source of irrigation water supply for agriculture, runoff for hydropower generation, and domestic water supplies in the western half of the United States. The exact effect of the climate change on snowmelt runoff is very difficult to predict.

Approach: Some common features of the climate change scenarios are chosen as input to the Snowmelt Runoff Model (SRM), a simple snowmelt runoff model which has been validated on over 75 basins worldwide. Three variables (temperature, precipitation, and snow covered area) are input to SRM to estimate the hydrologic response under conditions of climate change. Several representative basins in the mountainous western North America have been chosen for study.

Findings: In western North American basins, conventional depletion curves of snow cover will change under new climate regimes because of a warmer melt season as well as a warmer winter season. The warmer winter season features storm events with less snow and more rain and more winter snowmelt and runoff which results in less snow water equivalent on April 1 (if total precipitation is assumed unchanged). SRM can be used to compute year-round hydrographs in the existing climate and in an assumed warmer climate of the future. One reason for this is that SRM is a non-calibrated model which allows physical estimation of parameters under the projected conditions of the future climate.

In three basins studied, the winter runoff is nearly doubled in all basins in response to a +4°C increase in temperature. For a basin in the southwestern Sierras, the resultant proportion of the winter runoff (37.2%) is higher than the other basins because of the already warm present-day climate in the low elevation zones. Only in the Pacific Northwest basin (Illecillewaet River) does the annual runoff volume increase (+ 10.9%) after the warming. This increase results from additional melting of existing glaciers and permanent snow fields. In all basins, summer runoff peaks are shifted to earlier in the spring and summer months, evidence of the earlier beginning of the snowmelt season in a new climate.

Future Plans: The methodology developed on these representative snowmelt basins in North America will be extended to include changes in precipitation, clouds, and other atmospheric

effects. Comparison to hydrologic responses developed by other models will be attempted.

Publications 1996 - Present:

Rango, A., 1996. The response of areal snow cover to climate change in a snowmelt runoff model, Annals of Glaciology, 25, 5 pp.

Ritchie, J. and Rango, A., 1996. Remote sensing applications to hydrology: introduction, Hydrological Sciences Journal, 41(4), 429-431.

Rango, A. and Shalaby, A.I., 1996. Current operational applications of remote sensing in hydrology, Operational Hydrology Report, World Meteorological Organization, Geneva, Switzerland.

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Combining Improved Snow Cover Representations and Snowmelt Algorithms for Runoff Simulation Under Conditions of Climate Change

Principal Scientists: Albert Rango, William P. Kustas

Cooperating Scientists: Kaye L. Brubaker, Michael Baumgartner

ARS GCRP: Res. Areas: I; Prog. Elements: A; Objs.: 3; Tasks: 2.

CRIS Numbers: 1270-13610-004-00D

Problem: Most hydrological models, including the Snowmelt Runoff Model (SRM) include only a few climate variables as inputs that are likely to change with a new climate. A more physically-based and areally distributed SRM capable of accepting radiation, cloudiness, and albedo as well as temperature and precipitation inputs to calculate snowmelt is required to fully assess the effects of climate change.

Approach: A modular Alpine Snow Cover Analysis System (ASCAS) will be developed to monitor changes in snow cover in mountainous regions by both elevation and aspect. At the same time, SRM is being improved by the addition of a radiation-based snowmelt algorithm to make better use of the improved snow cover distributions available from satellite data and ASCAS.

Findings: ASCAS now allows data transfer between different software packages (i.e., image processing, geographic information systems, data base management, SRM, and scientific visualization). ASCAS is used to prepare snow cover data in a format for the improved SRM. Two versions of ASCAS are in preparation, one simplified version for use on PCs and one more sophisticated version for use on work stations.

A net-radiation index has been added to SRM, which formerly used only a temperature (degree-day) index to melt snow from a basin's elevation zones. The addition of radiation to SRM allows the basin to be subdivided into hydrologic response units by general aspect as well as elevation using ASCAS. Testing of the new radiation-based SRM with measured radiation from the small W-3 research basin in Vermont was successful. In 2 of 6 test years, goodness-of-fit statistics improved with the new radiation based approach and remained about the same in the other years. The new version of SRM was tested on the Rio Grande basin (3419 km^2) using publicly available snow cover data from on-line data sources. In general, the original and new versions of SRM give similar results on this large water supply basin. Testing of the new model on the Dischma basin in Switzerland in the climate change mode showed that the snowmelt calculation is very sensitive to not only temperature and precipitation changes, but also to cloudiness. The prevalence of thinner or thicker clouds after climate change can have as an important effect as a change in temperature. It is now possible to calculate the hydrologic response to climate change in snowmelt regions when the climate change scenario includes one or more of the following climate variables: temperature, precipitation, cloud amount, cloud type,

radiation, or snow cover extent.

Future Plans: Refinements are being made to the various ASCAS modules. The new improved SRM will be linked to ASCAS. The new radiation-based SRM will be tested next on a variety of years on large water supply basins in the western U.S. where the radiation melt component will need to be calculated based on commonly available radiation and cloud data or from time of year, latitude, and topographical information. Various climate change scenarios will also be tested on these large water supply basins. Documentation will be written to assist users in applying the new SRM.

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Quantification of Hydrological, Ecological, and Energy Balance Dynamics of Western Rangelands

Principal Scientists: Albert Rango, Kris Havstad

Cooperating Scientists: Jerry Ritchie, William P. Kustas, Tom Schmugge, John Prueger, Jim Everett, Frank Schiebe, Karen Humes, Larry Hipps

ARS GCRP: Res. Areas: I; Prog. Elements: A; Objs.: 1; Tasks: 5
Res. Areas: I; Prog. Elements: A; Objs.: 2; Tasks: 2
Res. Areas: I; Prog. Elements: A; Objs.: 3; Tasks: 4.

CRIS Numbers: 1270-13660-005-00D

Problem: There is a significant need to quantify and better understand the interaction of vegetation communities with the lower atmosphere, including feedback mechanisms arising from plant responses to changes in atmospheric and hydrologic fluxes. It is particularly important to obtain this information in a spatially distributed manner in order to quantify these relationships at various spatial scales.

Approach: Conduct a multilevel, multisensor field program at the Jornada Experimental Range in southern New Mexico during dry and wet seasons over a number of years to assess areal vegetation patterns and energy and water fluxes. Combine detailed ground measurements with aircraft remote sensing and satellite imagery in an attempt to scale up to large regions. Use historical data and current measurements to evaluate the response of rangeland vegetation communities to both short and long term changes in climate and management practices. Extend results from the Jornada site along a precipitation and vegetation gradient by making similar ground, aircraft, and satellite measurements at the Sevilleta National Wildlife Refuge, NM and the Central Plains Experimental Range, CO..

Findings: Intensive three day study periods for ground and airborne campaigns have been conducted in May 1995, 1996 and 1997 (dry season), February 1996 (dormant season), and September 1995, 1996 and 1997 (wet season). Thermal, multispectral, 3-band digital video, and laser altimetry profile and scanning laser data have been collected from aircraft platforms. Additional flights have been conducted with AVIRIS, TIMS, and TMS instruments. Bowen ratio-energy balance stations were established for long term measurements in the grass and shrub dominated communities. Periodic supplemental measurements have been made using eddy correlation techniques. Ground based measurements during the field campaigns include thermal and multispectral measurements as well as detailed spectroradiometer measurements. Measurements of vegetation species and height were made in support of the laser altimeter data and supplemented with leaf area index measurements. Ground and aircraft measurements were scheduled to coincide with Landsat-TM overpasses.

Preliminary results indicate that multilevel, multisensor remote sensing shows rangeland vegetation differences areally and temporally. Linkage to satellite multispectral satellite data

should provide more powerful information over larger areas. Remote sensing information at various levels provides a way to scale up from detailed ground studies in the Jornada. Remote thermal measurements of surface temperature have been used to calculate the sensible heat flux at the various Jornada test sites.

Future Plans: Data collection will continue for the Sept. - Oct. 1997 wet season at Jornada and Sevilleta. We hope to continue the measurements in Jornada for 1998 and extend the work along vegetation and precipitation gradients to include the Central Plains Experimental Range, CO to the north. We are working with ARS and LTER scientists in Colorado to establish the best flight lines. Future cooperation with NASA is anticipated at Jornada as part of their EOS validation program..

Publications 1996 - Present:

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Airborne laser measurements of landscape surface roughness

Principal Scientist: Jerry C. Ritchie

Cooperating Scientist: J.H. Everitt, K.M. Havstad, Y.A. Pachepsky, A. Rango, M.S. Seyfried, M.A. Weltz

ARS GCRP: Res. Areas: I ; Prog. Elements: A ; Objs: 2 ; Tasks: 2

CRIS Numbers: 1270-13610-004-00D, 1270-13660-005-00D

Problem: Data on complex patterns of surface features of the landscape are needed to understand their interactions with hydrological and biological systems. Determining these complex patterns of topography and landscape roughness features with conventional ground-based or aerial technologies is difficult and time consuming but measurements of roughness at different scales are necessary for understanding the effects of landscape roughness on hydrological and biological systems.

Approach: Airborne laser altimetry can provide detailed measurements for large areas of the landscape surface quickly. Airborne laser data provides high resolution information of the micro-roughness of soil and vegetation surfaces. The approach is to use this high resolution airborne laser data to estimate landscape parameters related to roughness.

Findings: Laser altimeter data have been used to quantify landscape topography, gully and stream cross sections and roughness and vegetation canopy properties. These properties and features are integral parts of the landscape and have to be measured and evaluated to understand the hydrology of natural and agricultural resources at large scales. Fractal parameters of laser altimetry data for the grass and shrub landscapes support the possibility of distinguishing between these landscapes using laser altimetry data. Results show that the fractal dimension is subject to seasonal changes and spatial variation in any specific range of scales. However, the pattern of the dependence of fractal dimensions on scale is specific to the land cover. The difference between fractal parameters of laser altimetry data for the grass and shrub landscapes supports the possibility of distinguishing between these landscapes using laser altimetry data. Studies have shown that estimations of aerodynamic roughness of a complex terrain consisting of coppice dunes with bare interdunal areas in New Mexico are possible using simple terrain features computed from high resolution laser altimeter data.

Future Plans: More studies on spatial and temporal variability of the roughness are needed to select formals ways to use laser altimeter data to quantify landscape roughness patterns and to use these data for distinguishing between land covers and estimating other parameters necessary for understand water movement on the landscape.

Publications 1996 - Pressent:

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Quantification of Spatially Distributed Fluxes with Remote Sensing

Principal Scientist: William P. Kustas

Cooperating Scientists: Tom J. Schmugge, Tom J. Jackson
Karen Humes, University of Oklahoma
John Norman, University of Wisconsin

ARS GCRP: Res. Area: I; Prog. Element: A; Objectives: 1; Tasks: 4, 5
Res. Area: I; Prog. Element: A; Objective: 2; Task: 1
Res. Area: I; Prog. Element: A; Objective: 3; Task: 4
Res. Area: V; Prog. Element: A; Objective: 1; Task: 1

CRIS Number: 1270-13610-004-00D
1270-13660-005-00D

PROBLEM: In order to properly address effects of global climate change on the environment, energy exchanges between the terrestrial ecosystems and the atmosphere need to be evaluated over a range of temporal and spatial scales. Remote sensing is the only technology which has the capability to integrate land surface characteristics and processes with the atmosphere, but interpretation of remotely sensed information is complicated because the signal is affected by many surface properties, including atmospheric effects.

APPROACH: To better interpret the remote sensing data and evaluate its utility in models for computing spatially distributed surface fluxes, large scale multidisciplinary field experiments are being conducted in different climates and terrestrial ecosystems. In these experiments, remote sensing data from ground, aircraft and satellite sensors are collected in concert with meteorological and energy flux data, including upper atmospheric data.

FINDINGS: Remotely sensed surface temperature data were successfully used in computing surface energy fluxes from local to regional scales using a physically-based two-source (i.e., soil-vegetation component) energy balance model. In addition, a two-source model was developed to use passive microwave data in mapping surface fluxes over a whole basin. A remote sensing model linking atmospheric boundary layer processes with time rate of change in surface tempereature shows potential for estimating regional surface fluxes with the operational GOES weather satellite.

FUTURE PLANS: Develop procedures for extrapolating surface fluxes from basin to regional scales using remotely sensed data in models simulating the interaction of terrestrial ecosystems with the atmosphere. Validate model predictions with data collected from several recent large scale field experiments (HAPEX-Sahel, Washita '92, Washita '94, JORNEX '95 and '96, the Southern Great Plains Experiment of '97) will be used to test remote sensing model algorithms.

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Anderson, M.C., Norman, J.M., Diak, G.R., and Kustas, W.P., 1996. A Simple Method for Estimating Surface Energy Fluxes and Air Temperatures from Satellite Observations. *IEEE IGARSS 96 Proceedings*. pp. 2104-2106.

The Use of Satellite Remotely Sensed Data for Land Surface Flux Determination

Principal Scientist: Thomas Schmugge

Cooperating Scientists: William Kustas - USDA/ARS Hydrology Lab
Simon Hook - Jet Propulsion Laboratory
Cesar Coll - Univ. of Valencia, Spain
John Norman - Univ. of Wisconsin
Toby Carlson - Penn State Univ.

CRIS Number: 1270-13660-005-08R

PROBLEM: Many new satellite systems for earth observations will be coming on line in next few years and the problem is to maximize the utilization of these new data sources as the they become available. In particular the multispectral thermal infrared data from the ASTER (Advanced Spaceborne Thermal Emission and Reflection radiometer) instrument to be flown in space in 1998 will be of interest for the determination of surface fluxes and surface state variables.

APPROACH: These future satellite data will be simulated with multispectral thermal infrared data acquired from aircraft platforms during recent field experiments. Land surface temperatures and emissivities will be extracted from these data for use in models to estimate surface fluxes.

FINDINGS: The algorithm being developed for use with the satellite thermal infrared to separate the temperature and emissivity of the surface was applied to multispectral thermal infrared data acquired from aircraft during the HAPEX field experiment in the Sahel with the TIMS sensor. TIMS provides coverage of the 8 to 12 micrometer thermal infrared band in 6 contiguous channels. The results show that the method works well and is relatively robust. The spatial resolution of these data was between one and four meters enabling us to separate bare soil and vegetation. The derived temperatures for vegetation were in excellent agreement with the ambient air temperatures. The emissivities for the soils were in good agreement with lab measurements made on these soils. The results from these activities will be used for the development of surface emissivity maps that can be used for surface temperature extractions with operational sensors and as such will be useful for applying satellite thermal infrared observations in global change studies.

FUTURE PLANS: Make use of the derived surface temperatures in models for estimating surface fluxes. Further validate the approach with data acquired during the various JORNEX campaigns and during this past summers Southern Great Plains Experiment.

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LONG-TERM HYDROLOGIC CHANGES

Principle Scientist: Keith R. Cooley
ARS CCRP: Res. Area: 1; Prog. Element: 1; Objs.: 2; Task 2.
CRIS Number: 13610

Problem: There have been documented increases in atmospheric carbon dioxide concentrations of about 43 ppmv since 1960. These steadily increasing concentrations of carbon dioxide could effect plant water use efficiency and thus the evapotranspiration and precipitation-runoff ratios of a basin (Figure 1). Slight suggested changes in the average surface temperature (less than .5° C). are within natural temperature variability and may not produce any identifiable change in hydrologic characteristics.

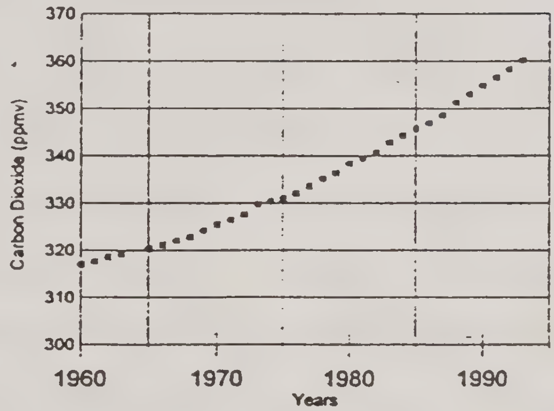


Figure 1 Atmospheric carbon dioxide concentration at Mauna Loa Observatory.

Approach: Long-term hydrologic watershed data at three scales were used to evaluate the effects of climatic change on hydrologic parameters and relationships. Individual parameters were analyzed to determine data quality and trends, then relationships between parameters were evaluated.

Findings: Double Mass plots of precipitation, snow and streamflow (i.e., accumulated snow at a site versus accumulated snow for a group of sites) indicated that precipitation and snow records are generally of very good quality as shown by a nearly straight line plot for precipitation site number 167 in Figure 2. A dramatic break in the slope of the line of points was noted for snow course number 144 after 1990 (Figure 3). This slope change can be attributed to timber harvesting

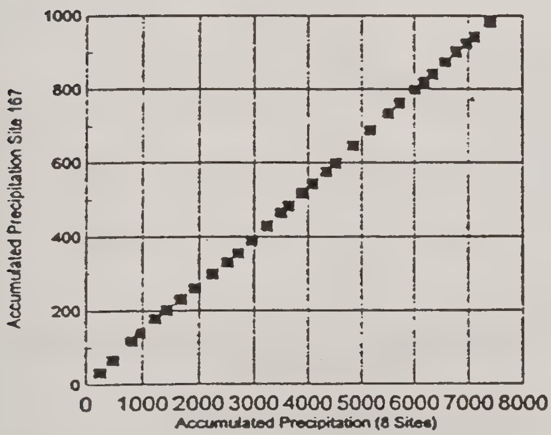


Figure 2 Accumulated precipitation for 8 sites versus precipitation for site 167.

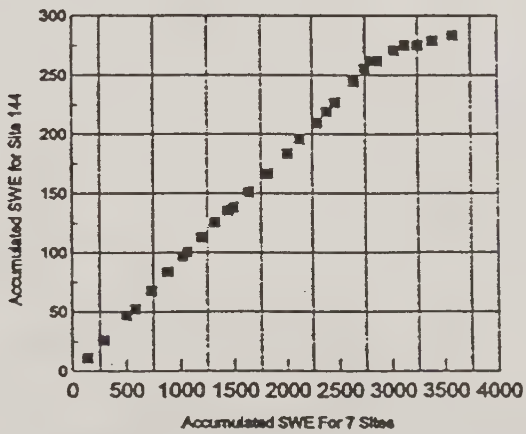


Figure 3 Accumulated SWE for 7 sites versus SWE for site 144.

adjacent to this site during the summer of 1990, that affected snow accumulation in the area. This type record should not be used for analysis of long-term trends. Streamflow records tend to deviate more from a straight line trend, typically alternating above and below the line due to the variable effects of wet and dry periods on different size basins with differing hydrologic characteristics.

Double mass plots of precipitation may not indicate long-term changes, because all stations used in the analysis are in the same general area and would probably be affected in the same way. However, if different variables are compared such changes may be noted. Changes in the relationship between precipitation and snow accumulation may be rather subtle unless storm patterns change significantly. Changes in the relationship between precipitation and streamflow however, could be dramatic for only minor changes in timing or amounts of precipitation. A plot of accumulated precipitation versus accumulated runoff for the 40 ha Reynolds Mountain basin shows minor deviation about a straight line for wet and dry periods, but no change in slope or relationship is observed (Figure 4). Similar plots for the 54 km² Tollgate and the 234 km² Outlet basins, indicated slightly more deviation on either side of a straight line, but no change in relationship. Plots using a group of precipitation sites rather than only one site produced similar results. Changes in the relationship between suspended sediment and either precipitation or runoff could be another indicator of climatic change, since erosion is a function of precipitation intensity and amount, and carrying capacity is a function of runoff volume and peak flow. Plots of sediment load versus precipitation or runoff indicated a near straight line relationship for the small Reynolds Mountain basin, somewhat more deviation about a straight line for the Tollgate basin, and considerable deviations or changes in slope for the larger Outlet basin. A plot of accumulated precipitation and sediment load for the Outlet basin (Figure 5) shows significant changes in the slope of the points, the steeper slopes being associated with wet periods and the flatter slopes with dry periods, but the overall trend for the entire period appears to remain unchanged. Thus the long-term data from Reynolds Creek would suggest that slight increases in temperature and steady more pronounced increases in atmospheric carbon dioxide have not produced observable changes in the hydrologic relationships.

Future Plans: Continue analysis with other variables (i.e., temperature)and publish results.

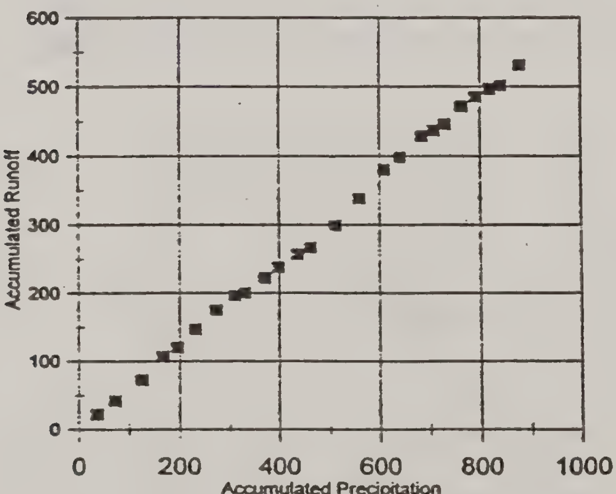


Figure 4 1969-1993 Accumulated precipitation versus runoff for Reynolds Mountain Basin.

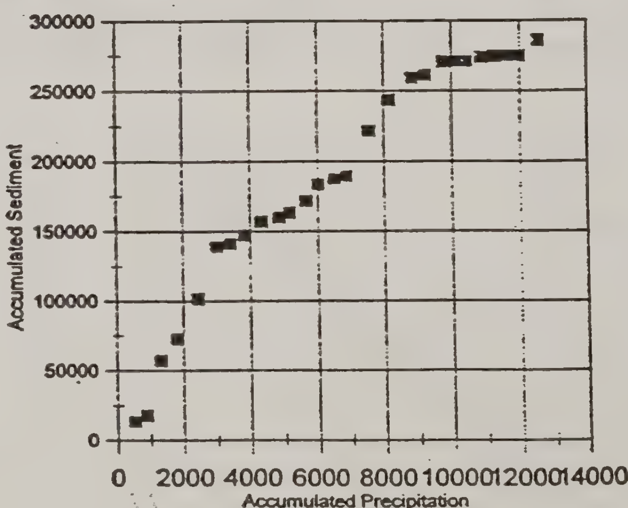


Figure 5 1967-1993 Accumulated precipitation versus sediment for the Reynolds Creek Outlet Basin.

TECHNICAL TOUR

ARS Global Change Workshop
Technical Tour
Wednesday, September 24, 1997

The tour will include the following stops:

-- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- **At Temple** -- -- -- -- -- -- -- -- -- -- -- -- -- -- --

Stop 1: **Indoor CO_2 Gradient Tunnel** - Hyrum Johnson

Stop 2: **Biological Control of Weeds** - Jack DeLoach and Paul Boldt

Stop 3: **Hydrologic Modeling** - Jeff Arnold

Stop 4: **Conservation Tillage** - Ken Potter and Allen Torbert

Stop 5:
a. **Mesquite Common Garden** - Charles Tischler and Rod Pennington
b. **Range Plant Competition Modeling** - Jim Kiniry

Stop 6:
a. **Outdoor CO_2 Gradient Tunnel** - Wayne Polley
b. **CO_2 Flux Measurements** - Bill Dugas

-- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- **At Riesel** -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --

Stop 7: **Hydrologic Research** - Kevin King and Clarence Richardson

Stop 8: **Vertisol Soil** - Ken Potter and Allen Torbert

Stop 9: **Mesquite Plot Studies** - Hyrum Johnson

Stop 10: **Native Grass Meadow** - Paul Mezynski

Stop 1:

From the Ice Age to the Present in a Subambient CO2 Gradient (SCG) tunnel: Effects of Increasing Atmospheric CO2 on Rangelands

Scientists: Hyrum B. Johnson, H. Wayne Polley, Charles R. Tischler.

The earth's vegetation has changed greatly during the Holocene. Atmospheric CO_2 concentration has roughly doubled (180 ppm to 360 ppm) over the last 15000 and increased about 30% during the last 200 years. Most plants, particularly C3 species are very sensitive to CO_2 increases over these past concentrations that are near their compensation point, the amount CO_2 produced in respiration equals the amount taken up in photosynthesis. Plants cannot grow and reproduce without taking up more carbon than they lose. It is easier with today's technology to develop systems for growing plants at elevated atmospheric CO2 concentrations projected for the future than it is to devise comparable systems for growing plants at CO2 concentrations atmospheric reminiscent of the past. The SCG was designed to study the effects that increasing CO2 has already had on plants and ecosystems.

The system is 38 m long and 0.45 m wide and rests on a soil bin that is 0.7 m deep. The 38 m length is in serpentine form with five approximately equal length sections fitted into a standard water cooled glass house. Each length of soil bin is divided into a series of 0.60 m x 0.45 m compartments, each with a soil volume of about 200 litters. The system is designed so that the experimental plants are an integral part of CO_2 control. Air introduced into the elongated chamber by a fan during daylight is progressively depleted of its CO_2 by photosynthesis as it moves along the chamber, resulting in a CO_2 concentration gradient that spans the range from the ice age to the present. The gradient is maintained by appropriate variation of the fan speed in relation to variation in light intensity and monitored departures of CO_2 concentration from a set point for outgoing air. The fan speed is controlled by computer algorithms developed specifically for maintaining the CO2 gradient constant. At night without light, CO2 is added air stream by plant and soil respiration and the CO2 concentration gradient is reversed. To minimize the magnitude of the reverse gradient the chamber is ventilated at night at a high flow rate with ambient air. Light, temperature and soil water are monitored regularly in the system. Water added to the system is carefully measured.

The chamber permits studies of the effects of changing atmospheric composition on plants and vegetation but also provides a vehicle for investigating the effects of plants and vegetation on the atmosphere. The isotopic signature of atmospheric CO_2 and water are influenced by plants. Plants discriminate differently against various isotopes of elements involved in photosynthesis and transpiration. In the case of carbon, plants (particularly C_3's) selectively remove ^{12}C from the air leaving the air enriched in the heavier ^{13}C. Because different plants discriminate differently between the ^{12}C and ^{13}C isotopes, the isotopic compsition of the atmosphere changes according to species composition of the vegetation. A quanitative assesiment of this relationship has important implications for the use of these isotopes in assesing change in a global context.

The CO2 gradient system has been in almost continuous operation since 1988. Several experiments have confirmed the hypotheses that plants should be highly responsive to rising CO_2 concentrations in the range experienced from glacial and more current time.

Growth at subambient CO_2 concentrations resulted in:

1. Plants species grown from the seed bank of the initial soil sorted themselves according to photosynthetic type along the CO_2 gradient with C_4 species thriving at glacial concentrations and C_3 species at current concentrations.
2. Growth of plants with the C_3 photosynthetic system respond strongly to increased CO_2 over subambient concentrations. Per unit increase in CO_2 concentration, the relative increase in growth of C_3 plants is 3 or more times greater in the subambient range studied here, than in commonly studied elevated (double current) range.
3. Nitrogen fixation of the legume, mesquite, was enhanced by present day atmospheres over those of the past.
4. Wheat yields at present day concentrations were three times larger than those at glacial concentrations and 50% greater than those of preindustrial times.
5. Survival of woody legume seedlings under comparable drought stress increased as CO_2 increased to the current concentration.

Selected Related Publications

1. Polley, H. W., Johnson, H. B., and Mayeux, H. S. Carbon dioxide and water fluxes of C_3 annuals and C_3 and C_4 perennials at subambient CO_2 concentrations. Functional Ecology 6:693-703. 1992.

2. Johnson, H. B., Polley, H. W., and Mayeux, H. S. Increasing and CO_2 plant-plant interactions: Effects on natural vegetation. Vegetatio 104/105:157-170. 1993.

3. Mayeux, H. S., Johnson, H. B., Polley, H. W., Dumesnil, M. J., and Spanel, G. A. A controlled environmental chamber for growing plants across a subambient CO_2 gradient. Functional Ecology 7:125-133. 1993.

4. Polley, H. W., Johnson, H. B., Marino, B. D., and Mayeux, H. S. Leaf delta ^{13}C, water use efficiency and yield of C_3 plants at glacial to present [CO_2]. Nature 361:61-64. 1993.

5. Polley, H.W., Johnson, H. B., and Mayeux, H. S. Increasing CO_2: Comparative responses of C_4 grass *Schizachrium scoparium* and grassland invader *Prosopis*. Ecology 75:976-988. 1994.

6. Polley, H. W., Johnson, H. B., and Mayeux, H. S. Nitrogen and water requirements of C_3 plants grown at glacial to present carbon dioxide concentrations. Functional Ecology 9:86-96. 1995.

7. Polley, H. W., Johnson, H. B., Mayeux, H. S., Brown, D. A., and White J. W. C. Leaf and plant water use efficiency of C_4 species grown at glacial to elevated CO_2 concentrations. Internat. J. Plant Science 157:164-170. 1996.

8. Polley, H. W., Johnson H. B., Mayeux, H. S., and Tischler, C. R. Are some of the recent changes in grassland communities a response to rising CO_2 concentrations, Chap. 12 (pp 177-195), *IN:* C. H. Korner and F. A. Bazzaz, eds. Carbon Dioxide, Populations, and Communities. Academic Press, Inc. San Diego, California. 1996.

9. Mayeux, H. S., Johnson, H. B., Polley, H. W., and Malone, S. R. Yield of wheat across a subambient carbon dioxide gradient. Global Change Biology 3:269-278. 1997.

Stop 2:

Biological Control of Weeds: Saltcedar and Musk Thistle

Scientists: Jack DeLoach and Paul Boldt

The Biological Control of Weeds Team, consisting of two research scientists, C.J. DeLoach and P.E. Boldt, is conducting research on controlling weeds in rangelands and natural areas of the southwestern United States. Major projects are control of two exotic invading weeds from Europe and Asia. These are the small tree saltcedar (*Tamarix ramosissima*) and musk thistle (*Carduus nutans*).

Saltcedar. Saltcedar (not related to cedars or junipers) was introduced into the United States around 1837 as an ornamental and for streambank stabilization. The genus *Tamarix*, with 54 species, occurs in the Old World from Spain, across the Mediterranean area, along eastern Africa, and across central Asia to Korea, China and central India. No species of the genus or of the family Tamaricaceae are native in either North or South America.

Some 10 species have been introduced into the United States. One of these, *T. ramosissima*, has become a major pest along streams and lakeshores from the central Great Plains to California and from Texas to southern Montana. This species has displaced the native riparian vegetation, especially of cottonwoods and willows, in many areas, and has destroyed large areas of prime wildlife habitat. The saltcedar invasion has also been a major factor in the declining populations of many wildlife species that are dependent upon western riparian habitats and several are becoming rare or endangered. Most native wildlife are poorly adapted to utilize the tiny fruits or seeds or the foliage or stems. Saltcedar also uses large amounts of groundwater, increases soil salinity, increases the incidence of wildfires, increases sedimentation and flooding and changes stream morphology to the disadvantage of many fish species.

Saltcedars are attacked by over 300 species of insects in the Old World, many of which are host specific and are able to feed and develop only on saltcedars. The methodology of the biological control program is to find insects that damage saltcedar in Europe and Asia, conduct intensive tests overseas and in quarantine at Temple, Texas, to insure that they do not feed upon or damage other plants and, after proper clearances and permits are obtained, to release the most effective of these insects into the field. Subsequent monitoring will determine the rate of spread and behavior of the released control agents and the amount of control obtained.

Two saltcedar-specific insects have now received preliminary approval for release on saltcedar in the US, pending approval of Biological Assessment with the US Fish and Wildlife Service and an Environmental Assessment. The Biological Assessment is necessary because the endangered southwestern subspecies of the willow flycatcher is known to nest in saltcedar in some areas. Once these issues have been resolved, we expect biological control of saltcedar to be very effective throughout most of the infested area of the west.

We expect biological control to result in substantial improvement of the native riparian plant communities and in the habitat of wildlife species that depend upon them, including the southwestern willow flycatcher and several other rare birds, fish and other animals. We also expect water tables to rise in some areas, for soil salinities to gradually decrease, and for the

incidence of wildfires to decrease. Herbicide usage and mechanical controls, which severely damage riparian vegetation, can decrease, resulting in both large cost savings and improved habitat.

Musk Thistle. Musk thistle, *Carduus nutans* L. complex is a growing weed problem in Texas. Infestations occur in overgrazed pastures, winter wheat fields and along roadsides. In Texas, this thistle has spread from an infestation in one county in 1940 to infesting in 28 counties in 1995. As part of out research mission, several approved biological control agents were imported into quarantine and released in Texas. The flowerhead weevil, *Rhinocyllus conicus* was first released on musk thistle in Kerr county in 1984. Presently, it has reduced musk thistle infestations at the release sites by 80 to 95% and spread several miles to other infested sites. The rosette weevil, *Trichosiroscalus horridus*, was released in 1991 and the syrphid fly, *Cheilosia corydon* was released in 1995. In addition, native thistles are monitored yearly to determine if they are attacked by any biological control agent.

Stop 3:
WATER MANAGEMENT MODELS SUPPORTED AT TEMPLE, TEXAS

OVERVIEW

Agricultural and water management models have been developed at Temple for more than 20 years. All models supported at Temple operate on a daily time step and are capable of long term simulations. Continuous time models allow simulation of ag management scenarios such as tillage, irrigation, nutrient, and pesticide application rates and timing. The models can be classified according to spatial scale. Field scale models include EPIC (Environmental Policy Integrated Climate), GLEAMS (Groundwater Loading Effects of Agricultural Management Systems), and ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria). EPIC is useful in solving management problems involving crop varieties and rotations, tillage, furrow diking, irrigation, drainage, fertilization, pest control, weather variation, atmospheric CO_2 concentration, erosion (wind and water), water quality (nutrients and pesticides), manure handling, crop residue management, liming, and grazing. GLEAMS is also a comprehensive field scale management model with strengths in pesticide leaching and fate. ALMANAC is a research model, adapted from EPIC that allows for plant competition. At the watershed scale, the SWRRB model (Simulator for Water Resources in Rural Basins) was designed for solving problems like water supply and quality, pond and reservoir design, and sedimentation. SWRRB provides for watershed subdivision (up to 10 subareas) to account for spatial variability in soils, land use, weather, and topography. This gives SWRRB the ability to estimate off-site impacts such as reservoir deposition and total water supplies. Current model development at Temple is focusing on two major thrusts. One is at the farm planning level with a new model called APEX (Agricultural Policy/Environmental eXtender). With APEX, farms may be divided into fields to simulate runoff, sediment, nutrients, and pesticides over complex landscapes. The other thrust is at the river basin scale (thousands of square kilometers) with a model called SWAT (Soil and Water Assessment Tool). SWAT allows a large river basin to be divided into thousands of cells or subwatersheds. Point sources, measured data, EPIC/APEX output, and output from another SWAT run can be input and routed with other simulated output. In addition to ag management capabilities for each subbasin, SWAT contains water management submodels that simulate irrigation water transfer, reservoir management, and water use withdrawals. GIS interfaces have been developed to manage, analyze, and display SWAT inputs and outputs. These models have been used throughout the world by various government agencies, universities, and consultants for non-point source and water supply planning and assessment.

WATERSHED/BASIN SCALE

SWAT (Soil and Water Assessment Tool) was developed by modifying the SWRRB model for application to large, heterogeneous river basins. Major changes to SWRRB include: (a) expanding the model to allow simultaneous computations on several hundred subwatersheds (the upper limit is 2500 subbasins) and (b) adding components to simulate lateral flow from the soil profile (0-2m), groundwater flow from the shallow aquifer (2-25m), reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams and valleys. SWAT operates on a daily time step and is capable of simulating 100 years or more. Major components of the model include surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, groundwater and lateral flow, and agricultural management. The SWAT model offers significant advantages over SWRRB. SWAT offers distributed parameter and continuous-time simulation, flexible watershed configuration, irrigation and water transfer, lateral flow, groundwater flow, animal waste simulation, and CO_2 submodels. The distributed parameter, continuous-time feature was achieved by developing a new routing structure. SWRRB routes from subbasin outlets directly to the basin outlet for simplicity. The new routing structure in SWAT is required to allow large basins to be simulated, provide more realistic routing, allow for more subbasins to be easily added, and simplify GIS linkages and database management.

SELECTED APPLICATIONS

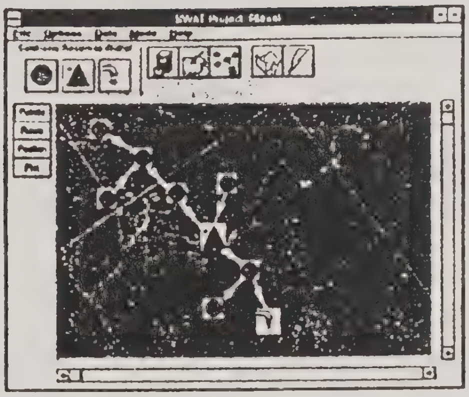
Field Scale

- 1985 RCA analysis
- Global climate change analysis
- 1988 drought assessment
- EPA nutrient movement study
- Soil loss tolerance tool
- Pesticide vulnerability analyses

Watershed/Basin Scale

- 1997 RCA analysis (HUMUS)
- Coastal Pollutant Discharge Inventory
- Pesticide assessment
- Water rights
- Urbanization impacts
- Regional crop planting date maps

Soil and Water Assessment Tool



CONTACTS

Jeff Arnold	Hydraulic Engineer	ARS-Temple	arnold@brcsun0.tamu.edu
Nancy Sammons	Computer Programmer	ARS-Temple	sammons@brcsun0.tamu.edu
Jimmy Williams	Hydraulic Engineer	TAES-Temple	williams@brcsun0.tamu.edu
Raghavan Srinivasan	Agricultural Engineer	TAES-Temple	srin@brcsun0.tamu.edu

MODEL OBJECTIVE

Predict the effect of management decisions and climate change on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungaged river basins.

MODEL COMPONENTS

Weather, surface runoff, return flow, percolation, ET, transmission losses, pond and reservoir storage, crop growth & irrigation, groundwater flow, reach routing, nutrient and pesticide loading, water transfer

MODEL OPERATION

- Daily time step-long term simulations
- Basins subdivided to account for differences in soils, land use, crops, topography, weather, etc.
- Basins of several thousand square miles can be studied
- Soil profile can be divided into ten layers
- Basin subdivided into subbasins or grid cells
- Reach routing command language to route and add flows
- Hundreds of cells/subbasins can be simulated
- Groundwater flow model
- Accepts output from EPIC
- Accepts measured data & point sources
- Water can be transferred from channels and reservoirs
- Nutrients and pesticide input/output
- Windows Interface
- GRASS GIS links to automate inputs and spatially display outputs

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Rosenthal, W.D., R. Srinivasan, J.G. Arnold. 1995. Alternative River Management Using a Linked GIS-Hydrology Model. Transactions of the ASAE, 38(3):783-790.

Srinivasan, R. and J.G. Arnold. 1994. Integration of a Basin-Scale Water Quality Model with GIS. Water Resources Bulletin. 30(3):453-462.

Srinivasan, R., J.G. Arnold, R.S. Muttiah, and P.T. Dyke. 1995. Plant and Hydrologic Simulation for the Conterminous U.S. Using SWAT and GIS. Hydrological Science and Technology, American Institute of Hydrology, 11(1-4):160-168.

USERS

- NRCS(Temple and other Locations)
- EPA
- Environmental Consulting Firms
- Texas River Authorities
- Universities
- NOAA

SWAT User's Manual Homepage: http://brcsun0.tamu.edu/swat/swat

Stop 4:

Conservation Tillage Plots

Soil: Houston Black clay (Udic Pellusterts) with 4.8% sand 33% silt and 56% clay.

Rainfall: 865 mm yr^{-1}

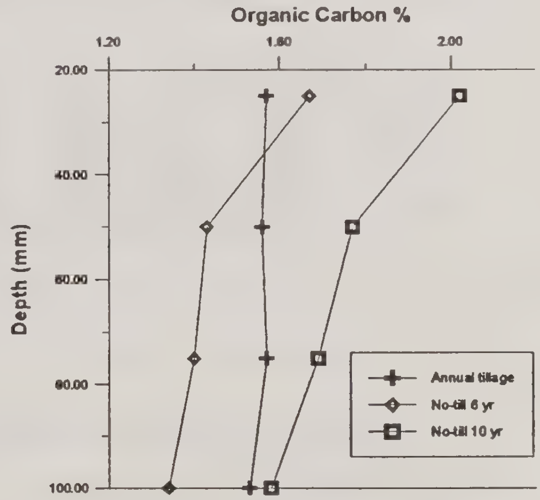
Management system: Raised wide beds (1.5-m wide separated by 0.5-m furrows) with annual tillage or no-till planting established in 1984

Crop Rotation: Winter Wheat\Grain Sorghum\Corn

Soil Carbon Concentrations Increased with Increasing Time in No-till

Potter and Chichester, 1993.

Soil Organic Carbon (SOC) content of the Houston Black soil increased with longer amounts of time in no-till management when compared to annually tilled soil. The greatest difference occurred in the top 100 mm of soil. The SOC concentration was uniform in the annually tilled soil because of the mixing which occurred during tillage.



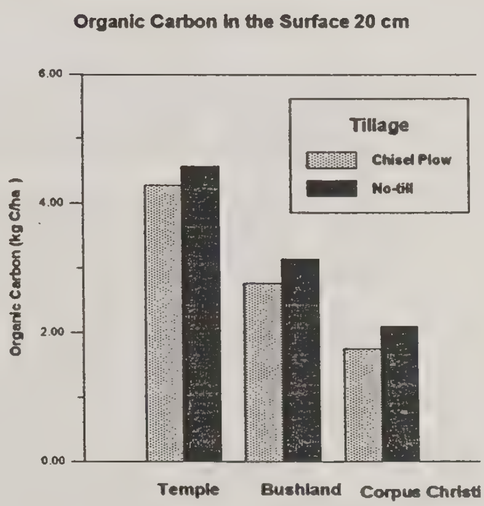
Distribution and Amount of Soil Organic Carbon in Long-term Management Systems in Texas

Potter et al., 1986: Potter et al., (submitted)

Management effects on SOC varied with climate and crop when comparing no-till with tilled soil management at three locations in Texas: Bushland, Temple, and Corpus Christi. Mean annual temperature had the largest effect on carbon sequestration in no-till compared to annual chisel plow tillage.

$$\Delta SOC = -0.17.2\left[AnnualTemp\left(^{\circ}C\right)\right] + 619$$
R^2=0.99

Including a fallow period in the rotation at Bushland negated the effect of no-till on carbon storage.

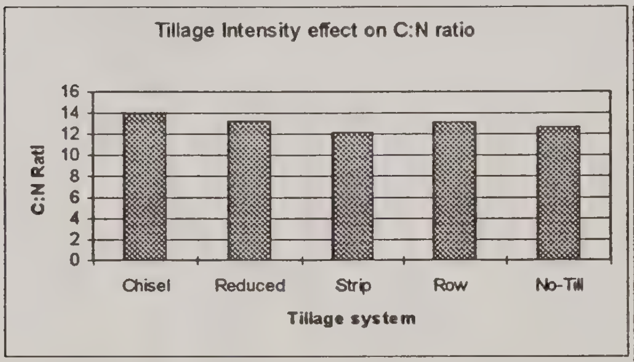


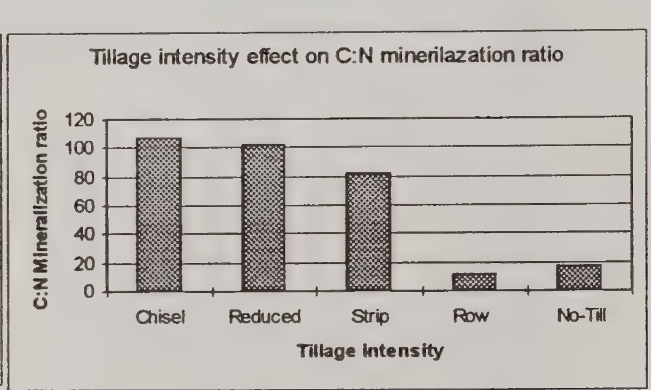
Stop 4:

Tillage intensity impacted the soil C and N cycling

Torbert et al., 1997

A soil incubation study was utilized to study the impact of tillage intensity on C and N cycling. The C:N ratio of soil was reduced as the level of tillage intensity was decreased. The C:N mineralization ratio, considered to be an index of the recalcitrant C levels in soil, decreased as the level of tillage intensity decreased . This indicated that the accumulation of organic C in the conservation tillage systems may be of more recalcitrant forms of C. Therefore, the more intensively tilled soil had a higher potential for C mineralization and a greater potential for reductions in soil organic C levels compared to less intensively tilled systems.





Residue cover had a greater effect on water infiltration than tillage system.

Potter, et al., 1995.

A rainfall simulator study compared water infiltration rates in no-till and annually chisel-plowed soil with and without surface residue cover. When the soil was dry, water infiltration rates were high for all treatments. After the soil had wet and swelled for two days, the infiltration rate was dependent on the surface residue cover.

30-minute cumulative infiltration (mm)				
	T/LR	T/HR	NT/LR	NT/HR
Dry	50	62	61	66
Wet	21	58	28	42

T/LR=Tilled/Low Residue: T/HR=Tilled/High Residue: NT/LR=No-till/Low Residue: NT/HR=No-till/High Residue.

Citations

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Torbert, H.A., K.N. Potter, and J.E. Morrison. 1997. Tillage intensity and fertility level effects on nitrogen and carbon cycling in a vertisol. Commun. Soil Sci. Plant Anal. 28:699-710.

Stop 5a:

Evaluation of Mesquite Half-Sib Families Collected Across a Broad Precipitation Gradient

Scientists: Charles Tischler, Rod Pennington, Wayne Polley, Hyrum Johnson, and Jim Kiniry, USDA/ARS, Grassland, Soil and Water Research Laboratory

Honey Mesquite (*Prosopis glandulosa var. glandulosa*) is a very common and troublesome brush species in the Southwest. Historical evidence suggests that mesquite occupied much of its current range before this area was settled by Europeans. However stand densities have increased greatly over the past 150 years, transforming the species from an often welcome source of shade and fuel to a ferocious competitor that has transformed productive range and pasture into non-productive shrubland. Various explanations for the recent success of mesquite have been advanced. Severe overgrazing, which has reduced competition from range grasses, is likely an important factor. Other changes in land use patterns, including suppression of fire and elimination of the prairie dog over most of its previous range, may also be important. The general degradation of soil fertility associated with overgrazing and erosion may also differentially favor mesquite (a nitrogen fixer) relative to native and introduced warm-season grasses. As mesquite distribution is generally limited to C_4 grasslands, preferential effects of the historical increase in atmospheric CO_2 on mesquite (a C_3 species) relative to resident C_4 grasses undoubtedly have modified competitive relationships between the shrub and grasses.

Honey mesquite flourishes from East central Texas (35 inch rainfall) to the Sonoran Desert in New Mexico (10 inch rainfall). Plant growth form differs along this precipitation gradient. In the eastern half of this range, very old trees, often single-stemmed, can reach a height of 30 feet or more, with a basal trunk diameter exceeding two feet. In the far western portion of its range, honey mesquite plants are typically multistemmed, less that eight feet in height, with stem diameters of one inch or less. Although morphologically dissimilar, these two growth forms are highly competitive with other associated vegetation in their respective environments.

For many species, water use efficiency (WUE) apparently correlates negatively with precipitation at the site of origin, suggesting that high WUE genotypes enjoy a selective advantage in drier environments. In light of the apparent influence of WUE on geographical distributions of plant species, as well as the strong link between WUE and photosynthetic parameters that can be impacted by rising atmospheric CO_2, we have begun to examine genetic variation for WUE in honey mesquite. Sixteen maternal half-sib families (20 seedlings per maternal tree) were grown in a glasshouse, and carbon isotope discrimination values (CID, a useful surrogate inversely correlated with WUE) were determined. Families were chosen from the wet and dry extremes of distribution of the species, as well as from points of intermediate rainfall. The experiment were repeated over two summers (1996-97). Large between-family variation in CID was observed, indicating the presence in mesquite of significant genetic variation for WUE. However, somewhat surprisingly, no trend of

increasing WUE with declining precipitation was observed. Instead, WUE correlated positively with precipitation.

As a continuation of this experiment, fifteen individual progeny of each of the 16 maternal parents were transplanted to a field nursery. This nursery serves three purposes:

> 1) Allows subsequent sampling of leaf material to determine CID values of plants at a more advanced growth stage, as the literature suggests that for some species the relative rankings of biotypes or genotypes based on CID differs between juvenile and adult plant forms. Such a result here would suggest that, in honey mesquite, seedling survival strategies differ from long-term growth or reproductive strategies.
>
> 2) Allows comparisons of mature growth forms of honey mesquite individuals from the wet (big tree) and dry (short shrub) areas of distribution of the species. If the differences in plant form are adaptive, or genetically based, then differences in growth form should be maintained in a common environment. The existence of such differences would provide additional insight into the role of genetic variation in invasion of mesquite across a wide range of environments.
>
> 3) Permits evaluation of the half-sib families from the eastern portion of mesquite's range to validate light interception values for use in the EPIC model. A very useful set of light interception values has been collected, but the trees examined represented a limited genetic base, being the progeny of only a single tree. Data from the additional families will offer more realistic input parameters for use in modeling PAR interception, leaf area development, and biomass of mesquite-dominated rangeland.

An important and novel aspect of this experiment involves the isolation of DNA from seedlings identified as having unusually high or low CID values. This DNA is being analyzed using the RAPD PCR method to identify molecular markers for WUE. Such markers will be used to characterize genetic variation for WUE present in mesquite plants *in situ* and will remove the need to conduct costly and time consuming common garden experiments.

A second experiment utilizing an additional 16 half-sib families from across the described precipitation gradient has also been performed. Parallel sets of seedlings were grown at current ambient and double current (700 uL L^{-1}) CO_2 concentrations, and sampled at time intervals to allow determination of relative growth rate. Specific leaf area (SLA) was determined and samples were taken for carbon isotope analyses. The objectives of this experiment were to identify relationships among CO_2 response and relative growth rate, SLA, CID, and site of origin. Data analyses have not been completed, but results should reveal the degree of intraspecific variation for CO_2 response present in the species . If significant intraspecific variation exists, then differential response to CO_2 may serve as a pool of variability on which natural selection may act, increasing the frequency of the more responsive genotypes and perhaps further increasing the competitiveness of mesquite on Southwestern rangelands.

Stop 5b:
Modeling Plant Competition

Scientist: J.R. Kiniry

Plant biomass can be simulated by leaf area index (LAI) development, the Beer's Law light interception function, and a species-specific radiation-use efficiency (RUE) for aboveground biomass. Drought or nutrient deficiency reduces simulated LAI and biomass growth. The objective of this field study in Texas was to compare the RUE values and leaf CO_2 exchange rates (CER) of four C_4 grasses. Biomass, LAI, and fraction of photosynthetically active radiation (PAR) intercepted were measured during three growing seasons. CER was measured on several dates, on several positions in the canopies. Switchgrass (*Panicum virgatum* L.) had the greatest RUE whereas sideoats grama (*Bouteloua curtipendula* (Michaux) Torrey) had the least. Big bluestem (*Andropogon gerardii* Vitman) and eastern gamagrass (*Tripsacum dactyloides* (L.) L.) were intermediate. RUE differences among species were not consistent with CER differences. Sideoats grama CER values were as great as those of switchgrass, whereas the RUE of sideoats grama was less than one-fourth as large. This discrepancy could not be accounted for by differences in partitioning to roots or by differences in production of soil carbon. Light extinction coefficients (k) showed the expected trend of switchgrass having smaller k than sideoats grama, implying that light was more effectively scattered over leaf area of switchgrass. However, concurrent CER and incident PAR readings showed that the mean efficiency ratios of CER:PAR were not greater for switchgrass. Only when the CER values of the canopies were estimated by stratifying the canopies into layers could the RUE differences be accounted for.

These results will be used along with three years of field results with eastern red cedar and honey mesquite to effectively model competition between brushy species and grasses with the ALMANAC model.

Stop 6a:
The Prairie CO_2 Gradient: Research with a View to the Past and Vision of the Future

Scientists: Hyrum B. Johnson, H. Wayne Polley, and Charles R. Tischler,
USDA/ARS, Grassland, Soil & Water Research Laboratory
William A. Dugas, and Patricia C. Mielnick,
Texas Agricultural Experiment Station
Robert B. Jackson,
Department of Botany, University of Texas

The Prairie CO_2 Gradient (PCG) is a unique controlled environment facility for exposing a portion of intact rangeland to a continuous gradient in atmospheric CO_2 concentration. The PCG provides for a uniform daytime gradient in CO_2 concentration from near the Ice Age (c. 18,000 years BP) level of 200 ppm to the current 360 ppm and from the current concentration to one predicted during the next century (550 ppm). The PCG is modeled after a prototype that has been operated with a subambient CO_2 gradient for almost 10 years in a glasshouse at Temple, and is comprised of two tunnel-shaped chambers aligned parallel to each other along a north to south axis.

The two chambers in the PCG each are 1 m wide and tall, and are composed of ten 5-m long compartments containing undisturbed soil and vegetation. During daylight, photosynthesis of enclosed vegetation depletes the CO_2 concentration of air as it is moved unidirectional through each chamber. The desired CO_2 gradient is maintained by automatically adjusting the rate of air flow through each chamber to changes in net CO_2 uptake by vegetation. Pure CO_2 is added during daylight to air introduced to the chamber on the east to elevate the initial CO_2 concentration to 550 ppm. A continuous gradient in CO_2 concentration from 550 to 360 ppm is maintained. Ambient air is introduced during daylight to the chamber on the west to initiate a subambient CO_2 gradient from 360 ppm to 200 ppm. The direction of air flow in each chamber is reversed at night and the CO_2 of air input to the east chamber is elevated. Air flow rates are regulated to maintain night-time CO_2 concentrations at 150 ppm above daytime values in each chamber.

Each of the 20, 5-m lengths in the PCG is separated by ducts with chilled-water cooling coils that are used to automatically reset air temperature and humidity to values measured outside chambers. Soil in each of the 20 lengths with undisturbed vegetation is isolated to a depth of 90 cm from surrounding soil with a rubber-coated fabric 3 mm in thickness. Air dry bulb and dew point temperatures and atmospheric CO_2 concentration are measured regularly at extremes of each 5-m length. Water is added through a surface irrigation system to match precipitation.

The PCG was constructed on a rangeland dominated by C_3 annuals in spring and the decumbent C_4 perennial grass *Bothriochloa ischaemum* (KR bluestem) and taller C_3 annual forb *Amphiacharis dracunculoides* (annual broomweed) during summer. Other warm-season C_3 forbs

occur at relatively low densities. The long-term annual precipitation of 825 mm is well distributed over the year, but often is insufficient to support growth from July through September.

Carbon dioxide treatments were initiated with the PCG in April 1997 to test two central hypotheses.

1. Increasing atmospheric CO_2 from near glacial through present to possible future concentrations will enhance net primary production and thereby contribute to an increase in short- to medium-term (years) C sequestration. Carbon accumulation rates will be monitored directly and continuously as net CO_2 fluxes between the atmosphere and the vegetation and soils in each of the 20, 5-m lengths along the PCG, and will be integrated over daily to annual scales to quantify effects of CO_2 on ecosystem C balance. Measurements of aboveground and belowground biomass will serve as a compliment to the C flux data.

2. Increasing atmospheric CO_2 concentration will reduce evapotranspiration and increase average levels of soil water, particularly during the usually dry summer. These changes will contribute to an increase in production and, possibly, abundance of species that previously were limited by low water availability. Evapotranspiration from rangeland in 5-m lengths of each chamber will be calculated from regular measurements of air dry bulb and dew point temperatures at extremes of each length. We will regularly measure xylem pressure potential on selected species, volumetric soil water content, and species composition across the CO_2 gradient.

Stop 6b:

MICROMETEOROLOGICAL MEASUREMENTS OF GRASSLAND CARBON DIOXIDE FLUXES

W.A. DUGAS AND H.S. MAYEUX

Measurements of carbon dioxide (CO_2) flux between the earth's surface and the atmosphere are useful for several purposes. ARS has established a multi-location research project wherein this flux is being continuously measured over grasslands at sites in the Western U.S. (Temple, TX, Woodward, OK, Ft. Collins, CO, Mandan, ND, Miles City, MT, Duboise, ID, Burns, OR, Tucson, AZ, and Las Cruces, NM). These flux measurements will be used to examine the effects of the environment and management on this flux and to infer the role of these ecosystems on the global carbon balance.

At all locations, the Bowen ratio/energy balance (BREB) method is being used to measure diurnal to seasonal CO_2 fluxes over grasslands (in some cases with two treatments, e.g. grazing or brush control), and to relate these fluxes to biotic and abiotic phenomena. Above and below ground biomass are sampled periodically. Half-hour CO_2 flux is typically measured from early Spring to late Fall. Soil CO_2 also is measured periodically. At some locations, midday canopy gas exchange measurements are made using pop-on chambers.

At Temple, measurements have been made at this tallgrass native prairie site every year since 1993. Typically, average daily evapotranspiration varies from less than 1 mm d^{-1} in March and November to just less than 5 mm d^{-1} in June and July. CO_2 fluxes also vary seasonally and are affected by leaf area, radiation, and soil water. Diurnal and daily CO_2 fluxes are typically near zero in the fall and spring and are maximum in the summer (Fig. 1). In 1993 and 1994, total annual CO_2 uptake was 200 and 295 g m^{-2} $year^{-1}$. The rate of dry matter accumulation calculated from these annual uptake rates was within 20% of the rate calculated from biomass measurements. These results suggest this prairie is in approximate equilibrium for carbon storage because estimated annual CO_2 uptake was near zero. However, results from a newly-sprigged, nearby bermudagrass field showed that it was a large sink for carbon (primarily in the roots) over the first two years after establishment (especially during the second year when the uptake was almost 3,000 g m^{-2} $year^{-1}$).

Flux measurements from all grassland sites are being collated and interpreted.

Stop 7:
Hydraulic Structures and Data Collection

Historical Perspective

In the mid 1930s, the Soil Conservation Service (SCS) determined a need to understand and analyze hydrologic data from natural field and watershed areas. A provision was made to create the Hydrologic Division of the SCS and establish a number of experimental watersheds across the United States. One of those watersheds was located near Riesel, TX in the heart of the Blackland Prairie on the Brushy Creek watershed. The primary function of the facility was to collect hydrologic data (precipitation, percolation, evaporation, runoff, etc.) from watersheds influenced by different land management practices.

The Blackland Prairie is a stretch of very fertile agricultural lands extending from San Antonio on the south to the Red River on the north. The dominant soils in this region are Houston soils which exhibit a strong potential for shrinking and swelling. The slopes are generally 1-3% and classified as gently rolling. The mean annual rainfall is roughly 850 mm. At present, land use in the watershed is primarily corn, sorghum, and oats. Pasture and grazing meadows can also be found. A full spectrum of tillage and management operations can be spotted throughout the watershed.

The Brushy Creek basin consists of government and non-government owned land. The Brushy Creek watershed spans a 2372 ha (5860 ac) area. At the station's prime a total of 35 runoff sites and 35 recording rainfall stations were in operation throughout Brushy Creek watershed. Since 1937, various types and amounts of data have been collected from the watershed area. The various types of data include rainfall volume and intensity, runoff hydrographs, sediment and nutrient losses, well heads, etc.

Major Findings

The original purpose of the watersheds was to determine the effects of conservation farming practices on the hydrology and erosion characteristics of the area. The experimental approach involved identifying one watershed as a control on which the farming system would remain the same as the prevailing practices in the area and selecting a second watershed to receive a conservation farming system. The results of this early study showed that erosion losses from the watershed receiving the conservation system was only one-eighth as much as that from the untreated watershed. Surface runoff from the conservation watershed was found to be 20% less than from the untreated watershed.

Since the original study, the watersheds have been used for numerous purposes such as water quality studies, the evaluation of specific farming practices, and as a source of data for model development and evaluation. The long hydrologic records on some watersheds (in excess of 60 years) make the data particularly valuable for studies designed to identify trends or changes caused by climate change or other factors. The watersheds continue to be a valuable resource for several types of hydrologic studies.

Present Day

Currently, 18 watersheds and 15 rainfall gauging stations are in operation. Present day instrumentation is located only on government owned lands. The current area of operation is approximately 250 ha. We are currently in the process of digitizing all historical data and making it accessible via the world wide web. We are also in the process of automating the data collection system. Rainfall stations have been re-instrumented with tipping bucket rain gauges and we are currently re-instrumenting the runoff stations. The stilling basins will be equipped with pressure transducers for recording gage height. After this process is completed we will connect all recording stations via telemetry.

The data available will include both breakpoint rainfall data and runoff volumes. Sediment loss will also be available. The data collected lends itself for long-term management comparisons as well as modeling validation.

Stop 8:

Vertisol Soil:

This stop will demonstrate some of the unique features of the soils of the Blackland region of central Texas. Classified as Udic Pellusterts, these are dark-colored deep soils which cover about 6 million hectares in a narrow belt extending from the Red River bottomland on the northern edge to the Rio Grande plain in the southwest. This region includes the major cities of Dallas, Austin, Temple, and San Antonio.

The dark color is not a result of high organic carbon content as much as the well dispersed nature of the organic carbon. Organic carbon contents in this region are generally < 2% in cropland and up to 6% in native prairie soils.

The vertisols are characterized as having a high montmorillionitic clay content, which results in a large shrink/swell potential as the soils wet and dry. Deep cracks (>0.5 m) form during the annual summer drought. The soils normally recharge during the winter months, causing swelling and producing an impermeable soil which results in large amounts of runoff during the early spring. Surface drainage is a desirable feature of conservation tillage systems on the Blacklands. These vertisols are often described as 'self mulching', forming a 10-15 cm layer of fine aggregates at the surface. The slaking of aggregates as the soils wet and dry causes this surface characteristic. The surface layer serves as an evaporation barrier, so the surface may appear dry but the lower horizons may be near saturation. The wet soil is unusually adhesive, clinging to shoes and machinery. People are often several inches taller leaving a field than when they entered.

A naturally occurring feature of the Texas vertisols is the gilgai, which a visiting Australian assured us as being an Aborigine word which translates as 'small waterhole.' This is appropriate as the gilgai in this region are circular and form a series of micro-high and micro-low topography which ponds water in the micro-low regions during wet periods. During dry periods, gilgai are often identified by the darker colored grass resulting from the additional water ponded in the micro-lows. The surface micro-topography also occurs in deeper soil horizons, usually in an exaggerated fashion, i.e. the micro-lows are much deeper than the micro-highs. Other gilgai may be linear, wavy, or form a feather pattern. Some are much larger and may form a small pond.

Gilgai are also characterized by the formation of 'slickensides' or very smooth surfaces that form between aggregates as a result of the high shrinking and swelling of these soils.

Stop 9:

Effects of Mesquite Invasion on Ecosysem Function and theQuality of Water Yield of Grassland

Scientists: Hyrum Johnson, Kevin King, Wayne Polley, Clarence Richardson and Allen Torbert
USDA/ARS, Grassland, Soil and Water Research Laboratory

The effects of changing vegetation on the quantity and quality of water yield from watersheds is of increasing importance as demands for water increase. Rangelands serve as the principle watersheds of many metropolitan areas of the world. In Texas, Dallas, Houston, and San Antonio depend on water from lands used for grazing. Mesquite and numerous other brush species are rapidly invading grazing lands of the western United States and other parts of the world. Many of the invading species, mesquite in particular, have notorious reputations as a extravagant water users that purportedly could greatly reduce water yields of invaded watersheds. A detailed understanding of the mechanisms and processes by which changes in vegetation structure and composition affect ecosystem functional relationships is lacking. Short term experiments designed to address this question have often produced contradictory results. In 1986 a long term study was established on four comparable small water sheds (¼ acre each) having a water yield measurement histories extending from the 1940's.

History of small artificially constructed watersheds P1, P2, P3 and P4.

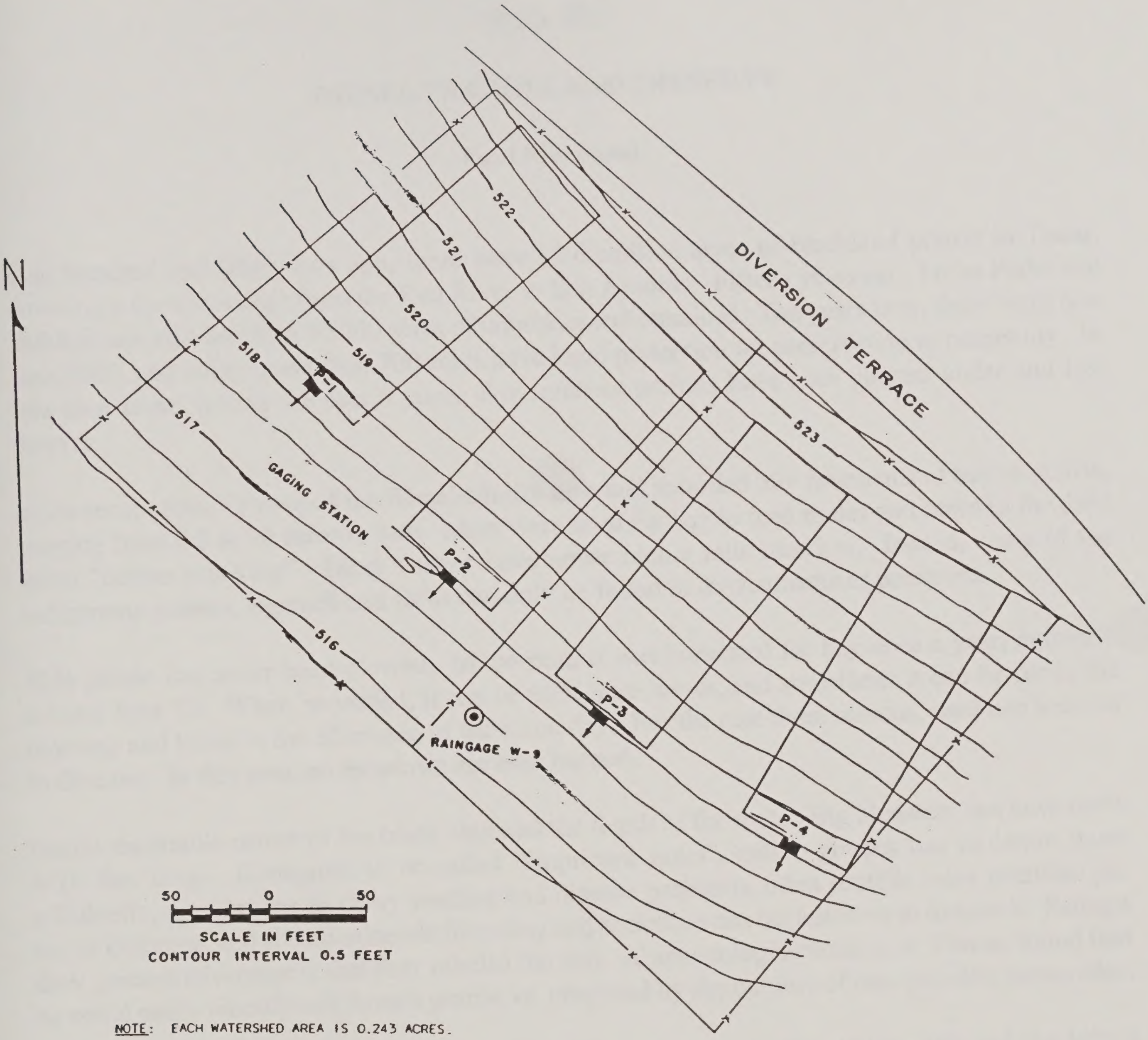
Studies on the watersheds began in 1938. Prior to that time a large diversion terrace was constructed to protect four, 1/4 acre watersheds, from up-slope run-on. Low dikes were raised around each watershed to delimit boundaries (see attached).
Experiments conducted on the watersheds can be divided into 4 periods each with a different objective:

1. 1938-1943. Cropping effects on water yield. Runoff was measured for crops of oats, cotton, and corn (rotation). In 1944 studies were discontinued and the area was sprigged to bermuda grass for pasture
2. 1960-1963, Effects of release from grazing on water yield. Watershed structures were restored and runoff measurements began as vegetation recovered in the absence of grazing.
3. 1964-1968, Effects of different intensitiesf of grazing on water yield. Light and heavy grazing treatments were imposed. The study was discontinued 1968 but site use as a pasture continued.
4. 1986-present, The effects of mesquite (*Prosopis glandulosa*), a legume, on the quantity and quality of runoff and ecosystem processes. Watershed structures were refurbished and updated. The site was fenced to prevent livestock use. Mesquite seedlings were planted at four densities, 0, 400, 1000 and 2500 individuals per hectare in May 1986. Mesquite plants that had previously invaded the pasture were removed

from only the 0 density watershed P4. Other mesquite invaders were noted, but left in place. Runoff measurements began in 1986. Automated water samplers were installed in 1993. Rainfall and runoff samples are being analyzed for N and P content. Runoff samples are being analyzed for soluble carbon. Three meter long clear acrylic tubes were installed to serve the dual role of minirhizotrons and access tubes for neutron moisture probes.

Summary of Rainfall and Runoff, Ranges and Averages, for the Four Time Intervals of Measurements of P1, P2, P3 and P4

Years Intervals	Ranges in Rain Inches	Ranges in Runoff Inches			
		P1	P2	P3	P4
1938-1943	27.5 - 42.7	0.3 - 8.9	0.0 - 11.8	0.3 - 10..9	0.0 - 11.3
1960-1963	19.0 - 38.4	0.0 - 6.2	0.0 - 7.1	0.0 - 7.2	0.0 - 9.7
1964-1968	30.8 - 47.1	0.2 - 10.2	0.1 - 11.4	0.5 - 13.4	0.4 - 12.4
1986-1994	26.4 - 53.9	0.1 - 8.1	0.2 - 8.6	0.2 - 8.7	0.2 - 6.2
	Averages of Rain and Runoff				
1938-1943	35.77	3.8	5.1	5.2	5.0
1960-1963	29.71	3.0	3.3	3.6	4.4
1964-1968	37.72	5.0	5.4	6.4	5.1
1987-1994	37.12	3.6	3.6	3.8	3.1



Watersheds P-1, P-2, P-3, and P-4, Riesel (Waco) Texas

Stop 10:

RIESEL PRAIRIELAND PRESERVE

Paul Mezynski

One hundred and fifty years ago, there were 12.6 million acres of blackland prairie in Texas, covering a narrow wedge from the Red River to San Antonio. Fifteen years ago, Texas Parks and Wildlife reported less than 10,000 acres of unbroken sod remained. Ten years later, there were less than 5000, and today fewer than 700 acres have legal protection for preservation in perpetuity. In this area alone, during the past 6 years, five remnant prairies have been plowed under and lost forever.

In the recent past, I surveyed the Riesel-Marlin area and recorded 50+ fragments of native prairie, varying from 0.5 to 30 acres in size. Most were used for hay to feed mules and cows in the days when “cotton was king”. Most Texans have never seen a relic meadow. Indeed, some of the indigenous grasses, legumes and forbs can only be found in the remnants or preserves.

This prairie has never been plowed. In the past, it was harvested for hay once a year, normally around June 15. When harvested, it can be 98% pure leaves, and sometimes it can be cut in the morning and baled in the afternoon of the same day. For the past three seasons, seed hay was cut in October. In this area, no meadows are ever burned.

Notice the friable nature of the black clay and the depth of the roots. Big bluestem can have roots 8-10 feet deep. Compared to so-called “improved grass”, native grasses use moisture more efficiently, are immune to many weather and disease problems, often provide more nutrition per ounce of forage, and absorb minerals from clay and rocks that can be passed on to livestock. Perhaps their greatest advantage is that they rebuild the soil. A nematologist working in Kansas found that he could easily identify soil from a prairie vs. cropland by the number of non-parasitic nematodes.

Native plants have been the focus of scientific research in the 1890's, 1910's, 30's and the 40's; a scenario of promotion, then discontinuance. The Native Prairie Association of Texas has expressed in writing its great disappointment in the recent discontinuance of native grass research at the Temple Ag Research Station.

SOME PLANTS IN THE RIESEL PRAIRIELAND PRESERVE

1.	Nemastylis geminiflora	prairie pleatleaf
2.	Andropogon gerardii	big bluestem
3.	Bothriochloa longipaniculata	longspike silver bluestem
4.	Bouteloua curtipendula	sideoats grama
5.	Elymus canadensis	Canada wildrye
6.	Eriochloa sericea	Texas cupgrass
7.	Panicum virgatum	switchgrass
8.	Panicum obtusum	vine mesquite
9.	Tripsacum dactyloides	eastern gamagrass
10.	Paspalum floridanum	Florida paspalum
11.	Phragmites australis	common reed
12.	Schizachyrium scopraium var. frequens	little bluestem
13.	Sorghastrum mutans	yellow indiangrass
14.	Polytaenia nuttallii	prairie parsley
15.	Cacalia plantaginea	groovestem Indian Plaintain
16.	Centaurea americana	American basketflower
17.	Engelmannia pinnatifida	Engelmann daisy
18.	Helianthus maximiliani	Maximilian sunflower
19.	Silphium laciniatum	compass plant
20.	Acacia angustissima	fern acacia
21.	Astragalus leptocarpus	slimpod milkvetch
22.	Desmanthus illinoensis	Illinois bundleflower
23.	Psoralidium tenuiflorum	slim-leaf scurfpea
24.	Schrankia nuttallii	catclaw sensitive briar